SUBCOURSE
EN5341

EDITION
A

US ARMY ENGINEER CENTER AND SCHOOL

GEOLOGIC ANALYSIS

Essayons

"LET US TRY"

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

A I P D

READINESS / PROFESSIONALISM THRU GROWTH

GEOLOGIC ANALYSIS

Subcourse EN5341

EDITION A

United States Army Engineer School
Fort Leonard Wood, Missouri 65473-6500

9 Credit Hours

Edition Date: July 1993

SUBCOURSE OVERVIEW

We designed this subcourse to provide you with a basic knowledge of the physical properties required to identify geologic materials, an understanding of the natural processes that act upon these materials, and the ability to classify the resulting soils.

There are no prerequisites for this subcourse.

This subcourse reflects the doctrine that was current at the time it was prepared. In your own work situation, always refer to the latest official publications.

Unless otherwise stated, the masculine gender of singular pronouns is used to refer to both men and women.

TERMINAL LEARNING OBJECTIVE

ACTION: You will identify and interpret characteristics and properties of basic geologic materials, as well as landforms derived from alteration and transportation of rock material due to external forces. In addition, you will also characterize and classify soils.

CONDITION: You will be given the information required to identify, interpret, characterize, and classify basic elements of geology and surface materials. You will need a Number 2 pencil and an Army Correspondence Course Program (ACCP) Examination Response Sheet (Army Training Support Center (ATSC) Form 328). A calculator is recommended.

STANDARD: To demonstrate competency of this task, you must achieve a minimum of 70 percent on the subcourse examination.

TABLE OF CONTENTS

These publications provide additional information about the material in this subcourse. You do not need these materials to complete this subcourse.

LESSON 1

ANALYSIS OF CONSOLIDATED MATERIAL (ROCKS)

OVERVIEW

LESSON DESCRIPTION:

In this lesson, you will learn to analyze terrain to determine basic rock types.

TERMINAL LEARNING OBJECTIVE:

ACTION: Identify the basic concepts of consolidated geologic materials, to include available information sources, rock classification and identification, engineering resource potential, and importance to military operations and planning.

CONDITION: You will be given information on the analysis of rock material.

STANDARD: Demonstrate the competency of the skills and knowledge involved in identifying and interpreting elements of basic rock identification according to FM 5-33 and TMs 5-545 and 5-330.

REFERENCES: The material contained in this lesson was derived from the following publications: FM 5-33, TM 5-545, and TM 5-330.

INTRODUCTION

The earth is made up of both consolidated material (rock) and unconsolidated material (soil). This lesson deals with the formation, mineral composition, classification, and identification of rocks. (Similar soil parameters are discussed in Lesson 3.) An understanding of the composition and properties of various rock types is important in assessing the location, quality, and quantity of construction resources; in siting roads and airfields; in rating the suitability of a site for construction of buildings and underground installations; in estimating the ease of excavation of shallow defensive positions as well as obstacles and barriers; in locating groundwater supplies; and in predicting soil types in areas where no direct data is available.

Because it is impossible to predict the ultimate military value of geologic information, all available information concerning the area of interest should be collected as standing operating procedure (SOP). Then, during operations, the actual geologic conditions encountered should be noted in order to update, verify, or modify the existing data bases and also to update intelligence estimates in cases where the new information has an impact on current operations. This type of information may have an important bearing on ongoing or future projects.

PART A - SOURCES OF INFORMATION

In performing a geologic evaluation, the terrain analyst utilizes several types of available source materials, including maps, imagery, and literature. In many areas, geologic maps of various scales already exist. If these maps do exis, the terrain analyst should exhaust all efforts to procure copies for the data base. Other useful materials required to update existing studies or to construct new studies include current 1:25,000 and 1:50,000 scale topographic maps, aerial photography at scales ranging from 1:20,000 to 1:40,000, land satellite (LANDSAT) or Systeme Probatoire d' Observation de la Terre (SPOT) imagery, and regional studies of landforms, geology, and geomorphology. These materials may be obtained from various governmental agencies (such as the United States Geological Survey, the Defense Mapping Agency, the National Aeronautics and Space Administration, the United States Soil Conservation Service, the National Forest Service, and state geological agencies) and private organizations as well as from books and periodicals. It is often necessary to use materials prepared by foreign governments or companies, such as reports available from numerous mineral and gas exploration efforts. The adequacy of source materials varies from one area to another; therefore, the analyst should use as many different sources as possible to achieve maximum accuracy and completeness of the data base. If the information sources are questionable, the analyst should annotate the uncertain reliability of the data. In some cases, there may be no source materials readily available, in which case it may be necessary to plan and request collection support. The collection of geologic information is an ongoing process whereby the analyst continually updates the data base with more current and increasingly accurate data. Once a sufficient amount of data has been collected, the analysis process begins with a critical review of the data base materials on hand.

1. **Maps**. In addition to geologic maps, there are three other basic map types available that can be used to construct a geologic overlay: topographic maps, surface configuration maps, and landform distribution maps.

a. **Topographic Maps**. Standard topographic maps displaying elevation and planimetric data are available at scales ranging from large (1:25,000) to small (1:1,000,000). Maps produced at large scales allow for the extraction of more information than those produced at smaller scales. However, geologic overlays are normally produced at scales of 1:50,000, so information derived from maps with scales other than 1:50,000 need to be reduced or enlarged to be used in conjunction with the overlays. In addition to the use of topographic maps for the extraction of relief and areal data, the analyst also uses them for the delineation of drainage patterns, which is a primary interpretation key in the determination of rock type and structure.

b. **Surface Configuration Maps**. These maps are usually produced at small scales (1:1,000,000 or smaller) and can be found in virtually any geography text or world atlas. They depict very broad categories of surface configurations. In general, these maps and associated descriptions will not provide the detail required for specific landform identification. However, they should be reviewed by the analyst for extraction of data in support of large-scale country studies and for general familiarization with a specific area of interest.

c. **Landform Distribution Maps**. Landform distribution maps, often called physiographic maps, are characterized by their large scales and detailed information; they

provide an excellent technical source of data. Because these maps are produced for a limited function and area, they may be difficult to locate, obtain, and reproduce.

2. **Remotely Sensed Imagery**. A remotely sensed image is any image of the earth's surface that has been recorded by a device not in physical or intimate contact with the object or phenomenon under study. These images can provide a large portion of the information required to analyze geologic data and construct a geologic overlay. Individual rock formations and structures, such as faults and folds, are often identifiable on remotely sensed imagery. The accuracy and detail that can be discerned from the image depend largely on the season and scale of the imagery as well as on the skill and knowledge of the analyst. There are two broad categories of imagery frequently used by terrain analysts in evaluating geologic conditions-aerial photography and multispectral imagery.

a. **Aerial Photography**. Aerial photographs are images of the earth's surface that have been recorded using airborne sensors which detect the reflectance of light in the visible or near-visible spectrum. The images may be either black and white (panchromatic) or colored. One especially useful type of aerial photograph is known as a stereopair (also stereoscopic pair or stereogram). A stereopair is made up of two photographs taken of adjacent areas in such a way that a portion appears on both photographs. For optimum stereoscopic (or three-dimensional) viewing, the photography should have a 60 percent overlap along the flight line and a 30 percent overlap along two adjacent flight lines. The best aerial photographs available are 9-inch by 9-inch prints with a scale of 1:20,000 or larger.

b. **Multispectral Imagery**. Multispectral imagery is imagery that has been obtained simultaneously in a number of discrete bands in the electromagnetic spectrum (not just in the visible or infrared part of the spectrum, as in aerial photography). LANDSAT and SPOT are two examples of multispectral imagery that can be used as an excellent source of information supporting regional analysis. The most common scale for this type of imagery is 1:250,000, but almost any scale can be obtained. It has been found that electromagnetic wavelengths of 1.55 to 1.75 microns and 2.00 to 2.35 microns (midinfrared range) are best for geologic interpretation. These wavelengths correspond to LANDSAT Bands 5 and 7. A course on multispectral imagery and interpretation will significantly improve the analyst's ability to request and interpret this imagery.

3. **Geologic/Geographic Literature**. This source of information is nearly unlimited in quantity, scope of subject matter, and coverage of geographic regions. The most useful literature contains information about a specific geographic area or a specific geologic feature and provides an understanding of the region physiographic divisions and major topographic landforms. Unfortunately, these sources are often too general to be of any real value to the terrain analyst. For this reason, area-specific literature should be reviewed by the terrain analyst as background source material only.

PART B - ROCK TYPE IDENTIFICATION

A rock is an aggregate of one or more minerals. (A mineral is a naturally occurring, inorganic compound that has a definite chemical composition.) Based on the principal mode of formation, rocks are grouped into three broad categories: igneous, sedimentary, and metamorphic.

Although each category is separate and distinct, natural processes exist that transform the rock types of one category to those of another, resulting in a constant recycling of earth materials without a net increase or decrease in the total amount of material on the earth. This phenomenon is referred to as the rock cycle, and it is diagrammatically represented in figure 1-1.

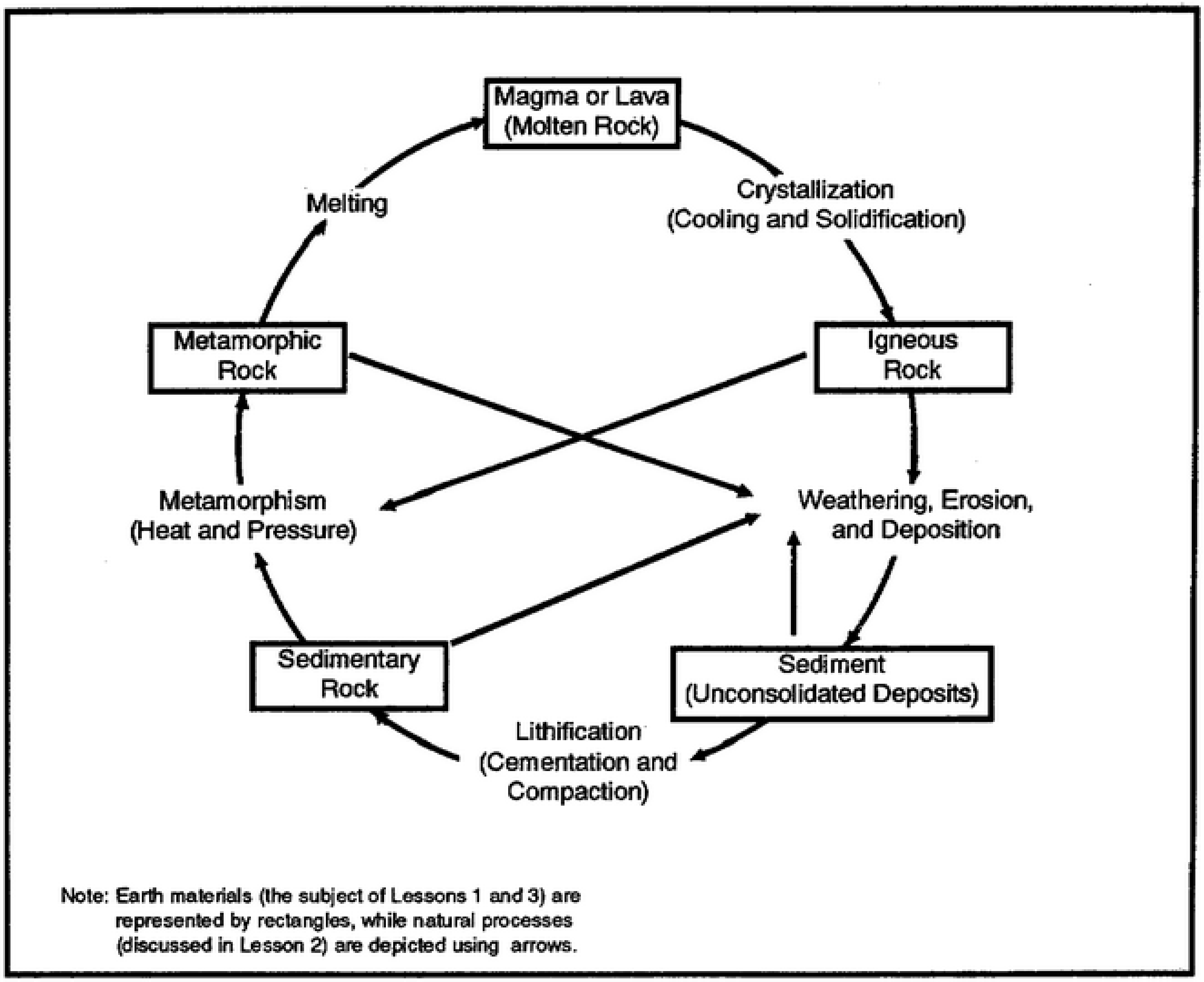


Figure 1-1. The rock cycle

Because an understanding of the composition and formation of igneous, sedimentary, and metamorphic rocks is essential for effective terrain analysis, each of these broad categories is discussed in further detail.

1. **Igneous Rocks**. Igneous rocks form from the solidification, or crystallization, of molten rock material. This molten material originates a magma deep within the earth where temperatures and pressures are extremely high. Because magma is generally less dense than the surrounding solid rock, and because it is somewhat fluid, it has a tendency to migrate upward along cracks and weaknesses in the overlying rock material. As the magma rises, it encounters progressively cooler temperatures, and at some point, it begins to crystallize. If crystallization takes place before the magma reaches the earth's surface, the resulting rocks

are termed intrusive, or plutonic rocks. However, if the magma does not solidify before reaching the earth's surface, the molten material that pours out onto the surface is called lava, and the rocks that crystallize from the lava are termed extrusive or volcanic rocks. Because intrusive igneous rocks crystallize at depths where conditions of temperature and pressure are not drastically different from those under which the original magma formed, the cooling rate is relatively slow and coarse-grained, or phaneritic, textures develop. On the other hand, lava cools very quickly upon exposure to atmospheric temperatures that are considerably lower than the initial temperatures of the molten material. As a result, there is not sufficient time for extrusive igneous rocks to develop large crystals; rather, a fine-grained, or aphanitic texture is formed. Three types of aphanitic textures occur: stony (the rock consists of individual mineral grains that cannot be discerned with the unaided eye), glassy (the rock cooled very rapidly, prohibiting the formation of any crystals), and frothy (the rock formed while gases were escaping from the lava so that small cavities, or vesicles, have been preserved). The texture of an igneous rock, coupled with its mineral content (roughly how light or dark the mineral is), is used to determine the rock type (see figure 1-2).

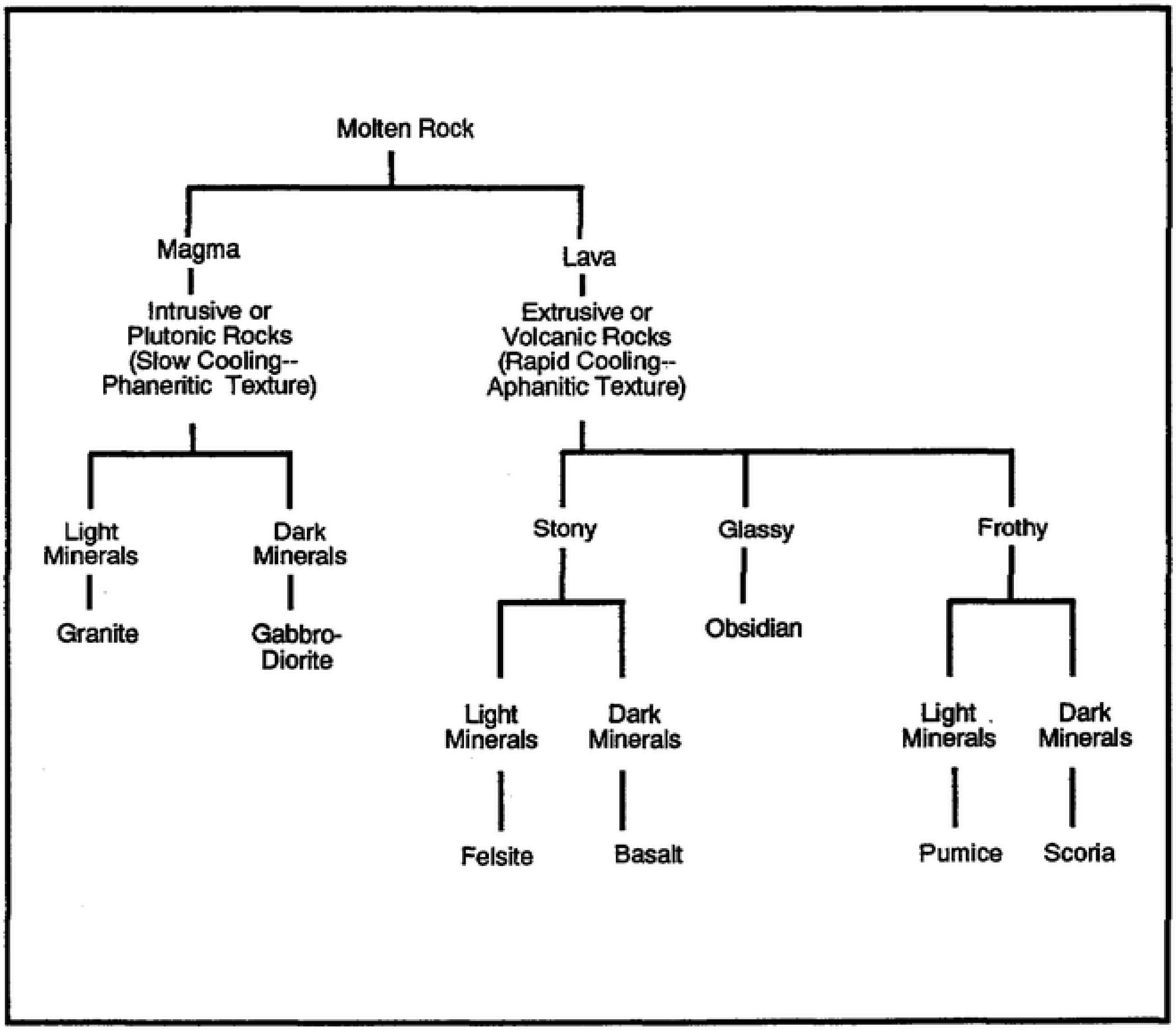


Figure 1-2. Classification of igneous rocks

Occasionally, igneous rocks of intermediate texture occur. Such rocks began to cool at depth so that a number of large crystals were formed. However, before the magma had a chance to completely solidify, it was forced further upward, allowing for more rapid cooling and the formation of correspondingly smaller crystals. The resulting rocks, which have several large crystals, or phenocrysts, embedded in a finer matrix, or ground mass, are said to exhibit porphyritic texture.

A final category of igneous rock, which is classified based on the mode of formation rather than on texture, is that of pyroclastic rocks. They are composed of individual volcanic rock fragments that were explosively or aerially ejected from a volcano and subsequently lithified, or cemented. Because these types of rocks are formed above the earth's surface, they are considered to be a type of extrusive igneous rock.

Characteristic rock bodies occur for both intrusive and extrusive igneous rocks. The most predominant of these is illustrated in figure 1-3.

a. **Intrusive Igneous Rocks**.

(1) **Characteristic Intrusive Rock Bodies**. Several different types of intrusive igneous rock bodies can be distinguished based on their relationships with the structure of the intruded, or country rock (see figure 1-3).

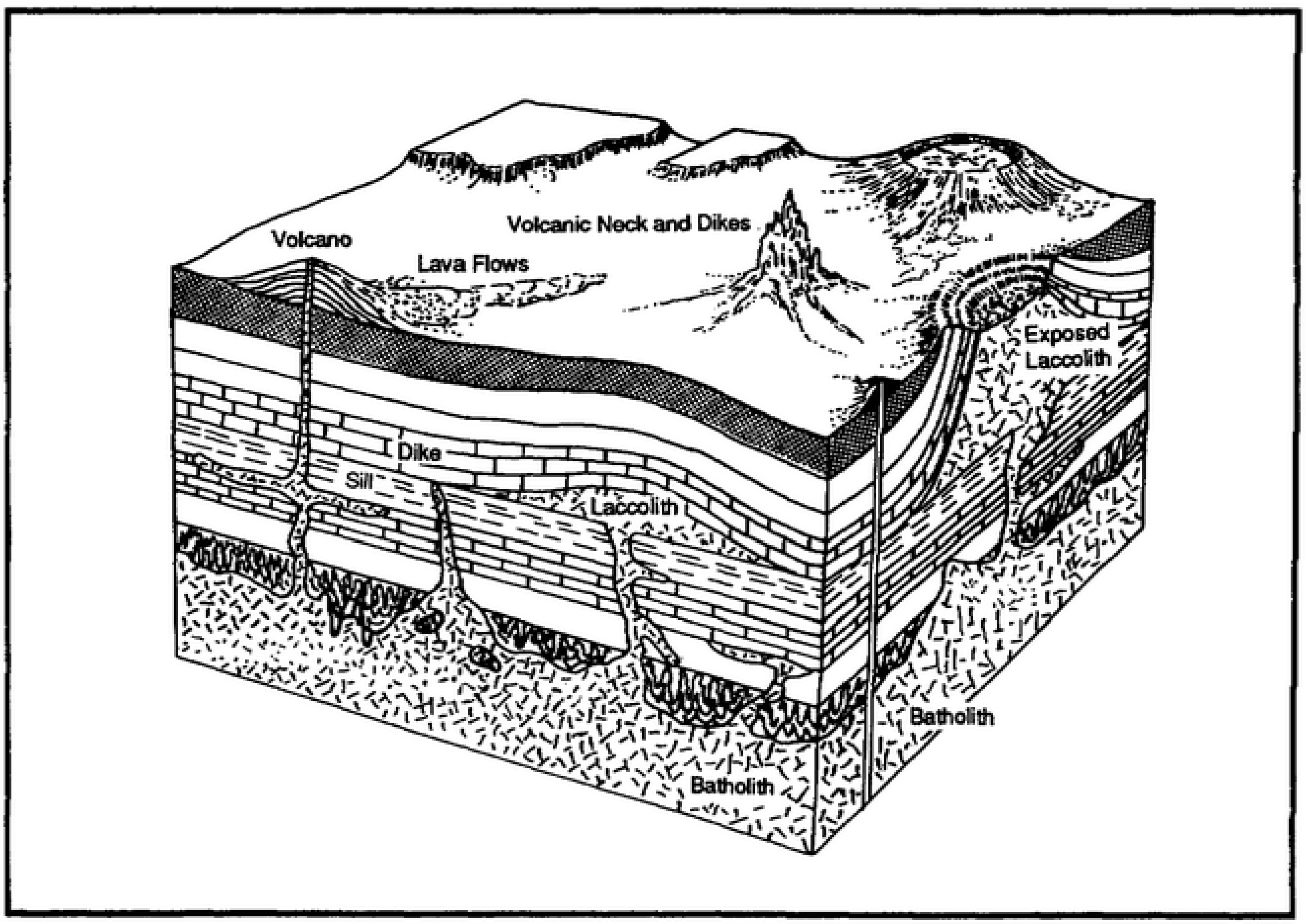


Figure 1-3. Intrusive and extrusive rock bodies

(a) **Batholiths**. The largest and deepest intrusive bodies are batholiths, which are the solidified remnants of magma chambers. Batholiths may be as much as 2,000 kilometers long and 200 kilometers wide, and they broaden downward to unknown depths. They often serve as the cores of folded mountain ranges.

(b) **Dikes**. These are tabular bodies of igneous rock formed from the solidification of magma as it travels upward through fractures in the overlying country rock. Due to the mode of formation, dikes cut across the structure of adjacent rocks; however, they terminate before reaching the earth's surface. Depending on the size of the original fracture, the thickness of a dike can range from a few centimeters to over a kilometer, and it may extend laterally for several kilometers. Dikes are commonly found radiating from a volcanic center, similar to the way the spokes of a wheel radiate from the hub.

(c) **Volcanic Necks or Volcanic Pipes**. If the upward movement of magma along a fracture is not halted at some depth below the surface but is, instead, allowed to continue until lava pours out onto the surface to form a volcano (see Lesson 1.B.1.b.(1)(a), page 1-12), the tabular intrusive igneous rock body formed is called a volcanic neck or volcanic pipe. These cylindrical masses may be as much as several thousand meters in diameter.

(d) **Sills**. A sill is a tabular mass of rock oriented parallel to the bedding planes of the enclosing country rock. Most sills are connected to a dike system and are formed when the magma, rising along a fracture, encounters a weak sedimentary layer and subsequently invades that layer. These intrusive bodies rage from a few centimeters to 1,000 meters in thickness; most are approximately 30 meters thick.

(e) **Laccoliths**. A laccolith is similar in origin to a sill. It is a large mass of igneous rock formed along a bedding plane. However, in this case, the magma pushes upward on the overlying rock formations, creating a domelike structure. The laccolith itself then takes on a lenticular shape.

(2) **Intrusive Rock Types**. For military purposes, intrusive igneous rocks are grouped into the following broad categories (see figure 1-2, page 1-5):

(a) **Granite**. This is the most predominant of the two intrusive igneous rock types and is composed of essentially light-colored minerals, such as orthoclase and quartz. In fact, it is common practice to apply the term “granite” to any light-colored, coarse-grained, intrusive igneous rock. Because of its mineral content, regions composed of granite exhibit a fairly uniform, light-colored tone on aerial photographs, except in areas of extensive surface roughness, where darker photo tones may be present. In addition, numerous joints, or fractures, which are represented by dark lines, may produce a “scrabbled” or scratchy photo tone in granitic regions.

(b) **Gabbro-Diorite**. Gabbro and diorite are actually two different intrusive igneous rock types that are so similar in appearance that they are often grouped into one category called “gabbro-diorite.” Gabbro-diorite is composed of predominantly dark-colored minerals, such as plagioclase, pyroxene, and hornblende. In the field, any dark-colored, intrusive igneous rock type is generally referred to as gabbro-diorite. These rock types are represented by dark photo tones on aerial photographs.

(3) **Relationship of Topography to Intrusive Igneous Rocks**.

(a) **Landforms Developed on Intrusive Igneous Rocks**. Extensive formations of intrusive igneous rock may be found throughout the cores of many eroded mountain ranges and in some areas of folded rock. In general, these massive batholithic intrusions are topographically expressed as domelike hills. In humid or temperate regions, the tops of the hills are gently rounded, and the side slopes are relatively steep, producing a "knobby" topography. In arid or semiarid regions, the hills are more angular. Figure 1-4 illustrates the topography of a batholith in the Rocky Bar, Idaho, area.

Intrusive igneous rocks, such as granite and gabbro-diorite, are often more resistant than the surrounding rock material. Therefore, in areas that have undergone extreme weathering and erosion, intrusive bodies may stand out in great relief. For example, volcanic necks, which originally crystallized below the earth's surface, may form a tower rising 1,000 meters above the surrounding country in highly eroded regions. Likewise, when exposed by the erosion of surrounding material, dikes take on the appearance of huge walls. Figure 1-5, page 1-10, is a topographic map of one such exposed volcanic neck and its associated radiating dikes.

(b) **Drainage Developed on Intrusive Igneous Rocks**. Because of the uniform nature of intrusive igneous rocks, dendritic (treelike) drainage patterns tend to develop on massive formations such as batholiths (see figure 1-4). However, a ringlike, or annular, drainage pattern may develop where streams flow away from the peak of a dome in a series of concentric fractures. In areas where extensive jointing has occurred, rectangular drainage patterns may develop (see figure 1-6, page 1-11).

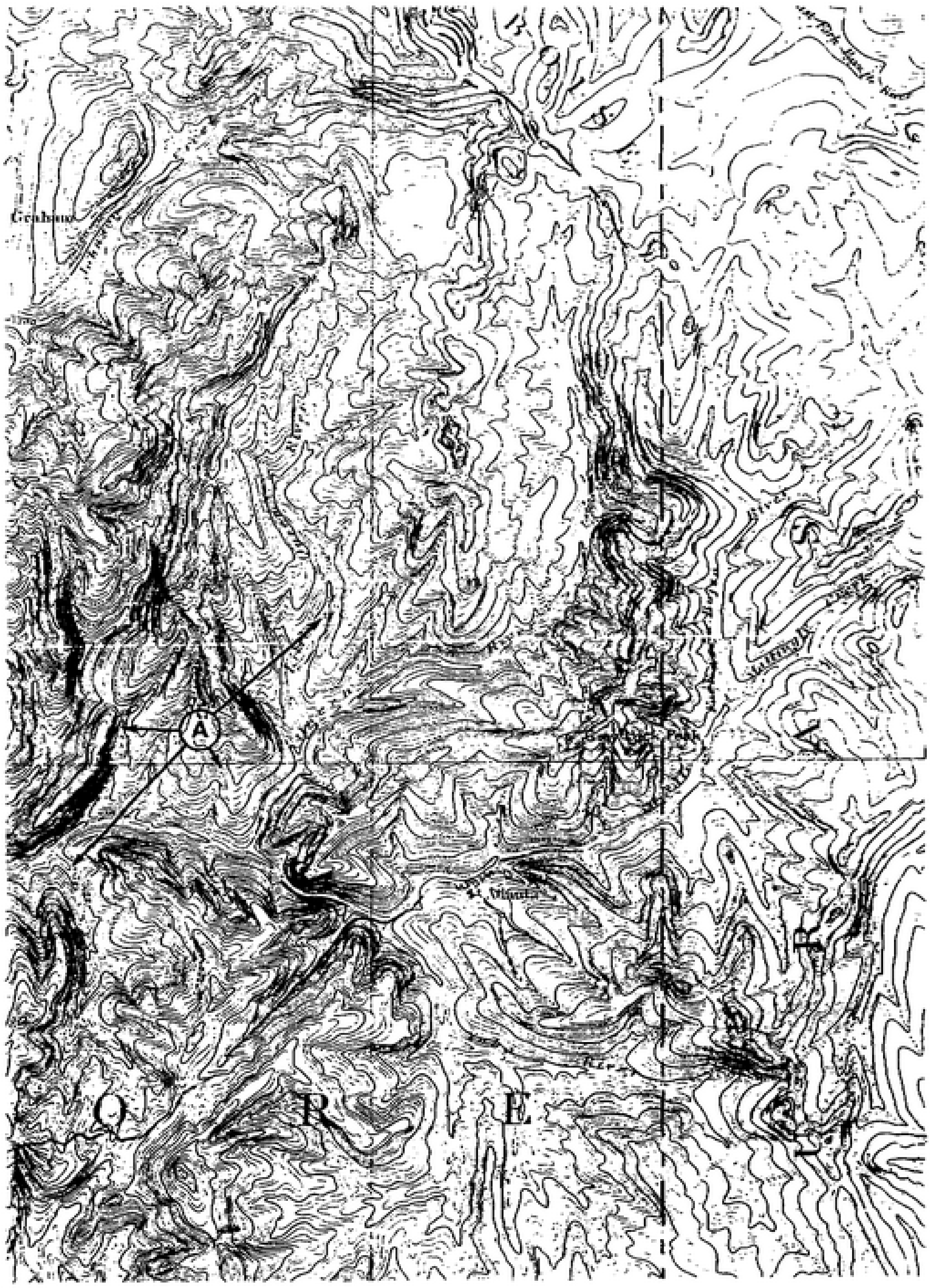
In arid regions where soils are shallow, gullies are seldom present. However, in humid regions, intrusive igneous rocks weather to form soil deposits consisting primarily of fine sands and fine, inorganic silts and clays. Gentle, U-shaped gullies are commonly formed on these types of soils.

(c) **Vegetation in Areas of Intrusive Igneous Rocks**. Vegetation on these rock formations is usually heavy in humid and tropical regions, while in arid regions, vegetation is sparse on the dome tops, with scattered vegetation aligned with the joints. Large areas of bare rock are also common in arid and semiarid regions.

(4) **Engineering Properties of Intrusive Igneous Rocks**. Both granite and gabbro-diorite are relatively tough, hard, and durable rock types. Furthermore, they are chemically stable, have good surface character, and produce a good crushed shape. As a result, these intrusive igneous rock types provide strong foundations and serve as excellent sources of construction material for both building stone and aggregate. Overall, intrusive igneous rocks display exceptional engineering properties.

b. **Extrusive Igneous Rocks**.

(1) **Characteristic Extrusive Rock Bodies**. Several different types of extrusive igneous rock bodies can be distinguished based on form (see figure 1-3, page 1-6). The most important of these are volcanoes and lava flows.



Note: Contour interval: 100 feet
A: Exposed portion of the Idaho batholith

Figure 1-4. Topographic map of Rocky Bar, Idaho

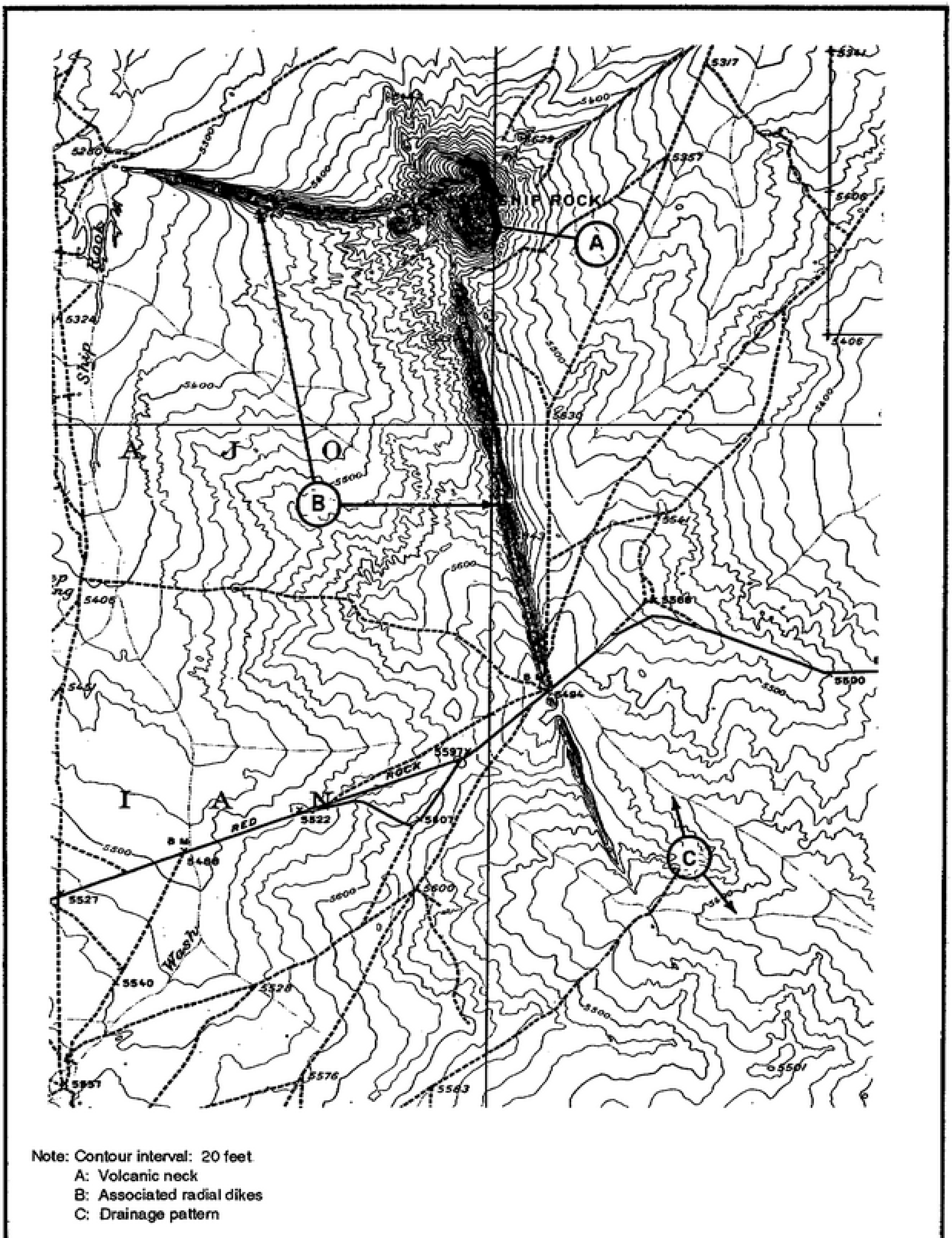


Figure 1-5. Topographic map of Shiprock, New Mexico

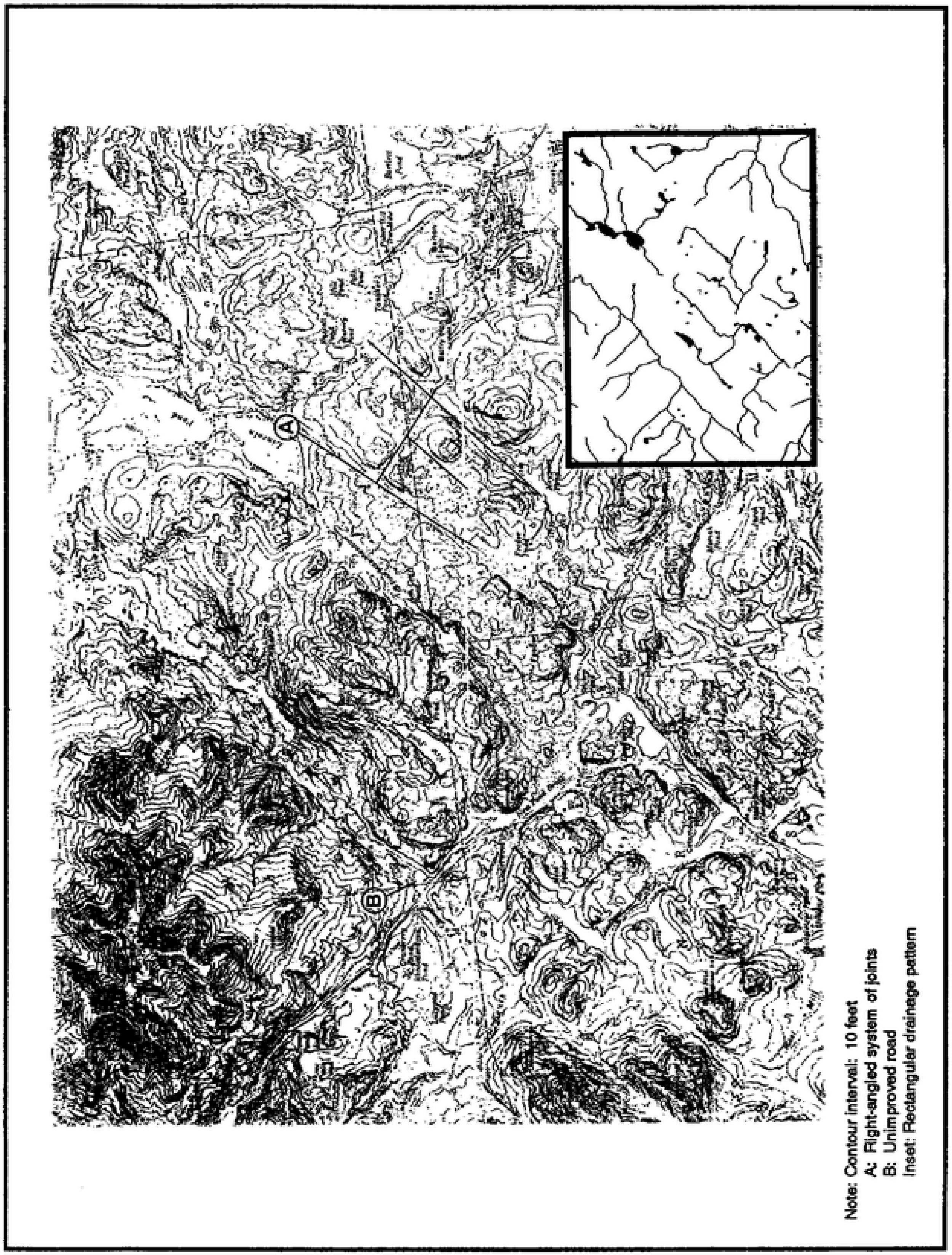


Figure 1-6. Topographic map of Elizabethtown, New York

(a) **Volcanoes**. When molten rock and hot gases, which have originated deep within the earth, rise to the point where they reach the earth's surface, they form an opening, or vent, through which they are extruded as lava. As the eruption continues, the molten material accumulates around the conduit, often creating a conical hill or mountain before solidifying. The combination of a vent and its associated cone is known as a volcano. Volcanoes vary greatly in size, ranging from very small hills to some of the loftiest mountains on earth.

(b) **Lava Flows**. If molten material extruded at the earth's surface is too fluid to accumulate around the opening, a volcanic cone may not develop. Instead, the lava may outpour laterally, creating extensive sheets of extrusive rock called lava flows. A distinctive characteristic of lava flows is columnar jointing, a type of jointing in which five- or six-sided vertical columns a few inches in diameter are formed as the molten rock shrinks during cooling. Successive, intermittent outpouring of lava flows in a specific area may result in layered deposits thousands of feet in thickness.

(2) **Extrusive Rock Types**. Extrusive igneous rocks may reach the earth's surface as either a lava flow or a pyroclatic ejection of fragments. In the case of a lava flow, the resulting extrusive igneous rocks develop one of three types of aphanitic texture--stony, glassy, or frothy. Pyroclastic materials exhibit their own unique characteristics.

(a) **Stony Texture**. Extrusive igneous rocks with a stony texture are dull in appearance and contain very few vesicles, indicating a lack of trapped air bubbles. There are two major types of extrusive igneous rocks with a stony texture-felsite and basalt.

- Felsite is a light-colored, fine-grained, extrusive igneous rock with a stony texture. The chemical composition of rhyolite, a specific type of felsite, is identical to that of granite; the only difference between the two is the size of individual component grains. Felsite displays relatively light photo tones on aerial photographs, because of its light color.

- Basalt is a dark-colored, fine-gained, extrusive igneous rock with a stony texture. It is the aphanitic chemical equivalent of gabbro-diorite. Basalt is the most common and widespread type of extrusive igneous rock. Many volcanic islands, such as the Hawaiian Islands and Iceland, are composed primarily of basalt. Basalt displays dull, dark gray to black photo tones on aerial photographs because of its naturally dark color. Scattered light spots are common, indicating variations in soil cover. One distinctive feature of basaltic lava flows is a mottled pattern referred to as “snake skin” or “lizard skin.” In addition, a “dried blood” pattern may exist on air photos where isolated patches of fluid basalt have broken through overlying basaltic crust.

(b) **Glassy Texture**. The only extrusive igneous rock with a glassy texture is obsidian. Obsidian is a dark, silvery-gray to black rock that underwent extremely rapid cooling. Extrusions of obsidian are generally not extensive enough to form readily identifiable photo characteristics.

(c) **Frothy Texture**. Frothy rocks contain numerous vesicles formed as gas bubbles were escaping from molten igneous rock material. There are two types of extrusive igneous rocks that exhibit a frothy texture-pumice and scoria.

- Pumice. This is a light to medium gray, frothy, extrusive igneous rock. The large amount of void space in the rock causes it to have a very low density. (Pumice is the only rock that will float on water). Flow marks or blisters present in these types of flows may sometimes be distinguished among the light photo tones on aerial photographs.

- Scoria. This is a fine-grained, frothy, extrusive igneous rock with an appearance similar to that of pumice. However, scoria is dark-colored, ranging from shades of brown to black or brick-red, and it is more dense than pumice. (Scoria will sink in water.) Scoria appears dark on aerial photographs; however, it may still be possible to distinguish flow marks and vesicles within the flow region.

(d) **Pyroclastic Materials**. Fragments of solid rock material aerially ejected from volcanic vents are collectively referred to as pyroclastic material. The size of the rock fragments ejected from a volcano range from fine dust or ash through volcanic sand, lapilli, cinders, and bombs to large blocks. These rock fragments may, at some later time, become consolidated to form a pyroclastic rock. Such rocks, composed of volcanic dust and ash, are called tuffs, whereas the term volcanic breccia is generally reserved for pyroclastic rocks made up of fragments greater than four millimeters in diameter. Consolidated pyroclastic rocks are photographically similar to sedimentary rocks, which are discussed in Lesson 1.B.2, page 1-18.

(3) **Relationship of Topography to Extrusive Igneous Rocks**.

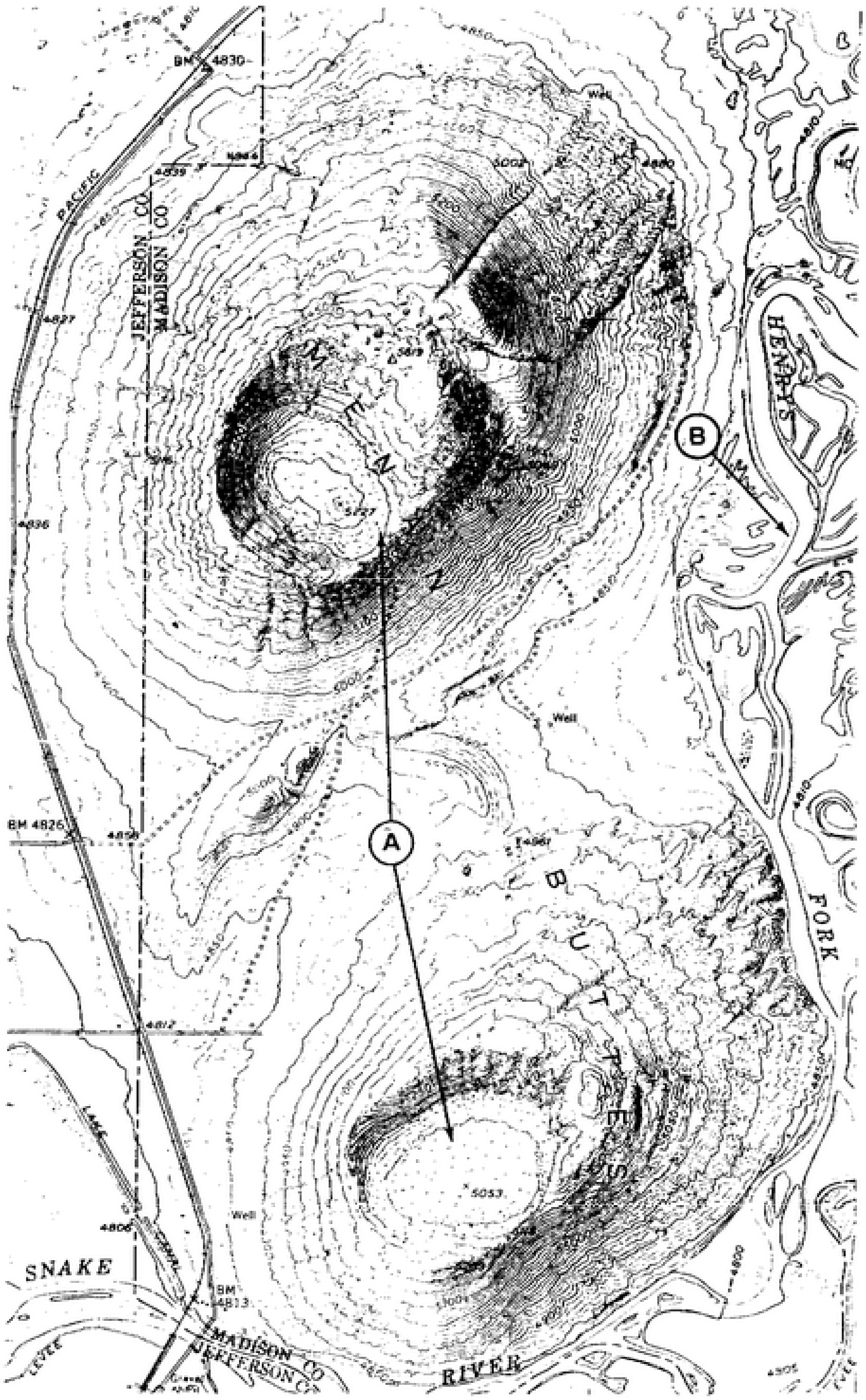
(a) **Landforms Developed in Areas of Extrusive Rocks**. The extrusive igneous rock bodies previously discussed (volcanoes and lava flows) may be readily identified by their characteristic landforms. In fact, three different types of volcanic cones may be distinguished based on their topographic expressions.

- Cinder cones are steep-sided, symmetrical cones composed of angular fragments of rock ejected during volcanic eruptions. If the fragments are large, the side slopes of the cone will be inclined at angles of 30 to 40 degrees from the horizontal. If the pyroclastic material is fine-grained, the side slopes are more gentle. Figure 1-7, page 1-14, illustrates the topography of two weathered cinder cones, covering approximately eight square miles.

- Shield volcanoes are very broad, slightly arched “cones” resulting from outpourings of fairly fluid lavas. The most notable shield volcanoes are those of the Hawaiian Islands. Two such volcanoes are depicted in figure 1-8, page 1-15.

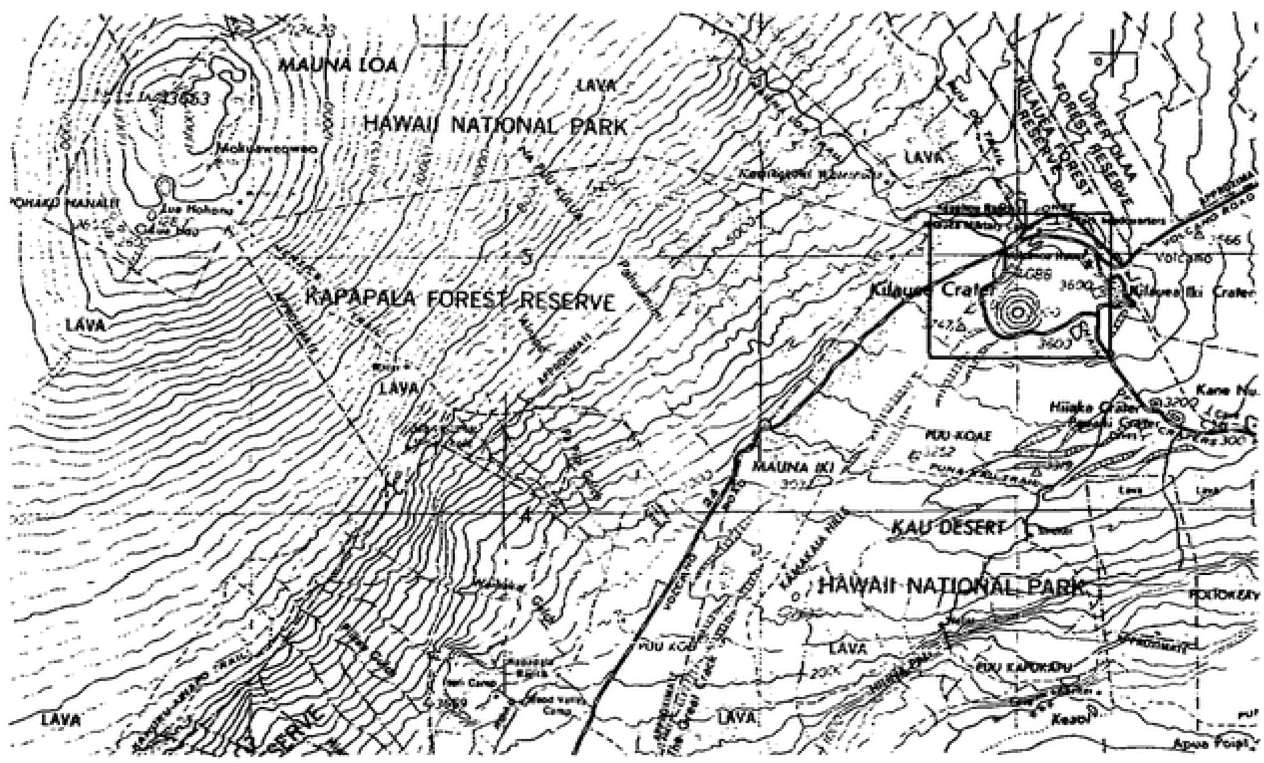
- Composite cones are composed of alternating layers of lava flows and rock fragments. The side slopes of these volcanic cones are intermediate between those of cinder cones and those of shield volcanoes. An example of a large composite volcano can be seen in figure 1-9, page 1-16.

- Lava flows, in contrast to the marked relief of volcanoes, form extensive plains and plateaus. Young flows have a level to gently sloping surface, and lobate edges marking the terminus of the flow may yet be visible. Mature flows, on the other hand, are highly dissected, with a surface of rolling to rugged hills. The distinctive topography associated with young extrusive flows will rapidly disappear in humid climates, and a thick soil profile will develop. The region shown in figure 1-10, page 1-17, is composed of several isolated basaltic mesas, a common feature of mature lava flows.



Note: Contour interval: 10 feet
A: Weathered tuff cones
B: Half-interval contour

Figure 1-7. Topographic map of Menan Buttes, Idaho



Note: Contour interval: 250 feet
Shield volcanoes. Kilauea Volcano is located
on the southeast slope of Mauna Loa.

Figure 1-8. Topographic map of Mauna Loa and Kilauea, Hawaii

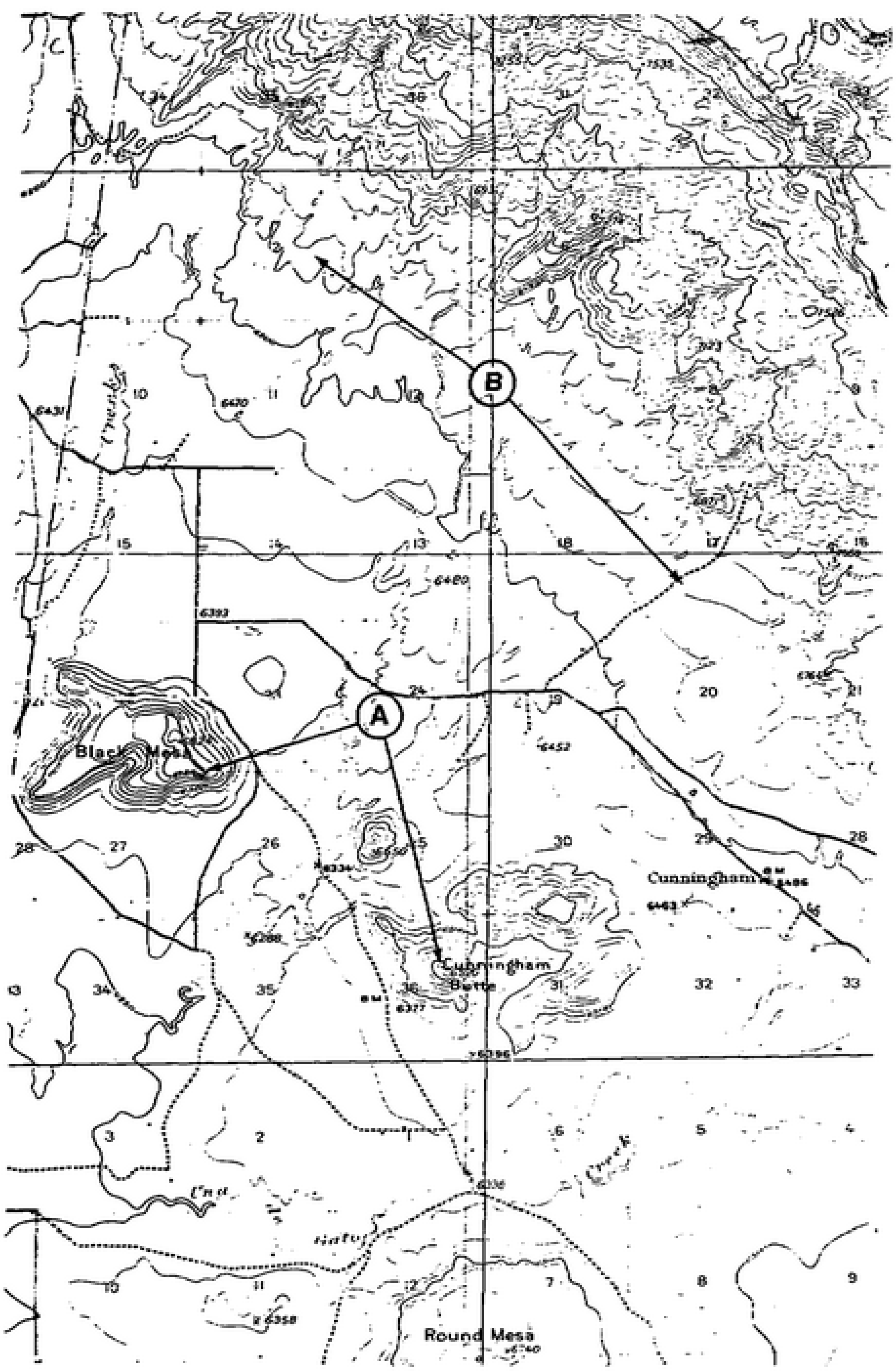
(b) **Drainage Developed on Extrusive Rocks**. In areas of volcanic cones, streams generally radiate from the center of the cone, forming a radial drainage pattern. On flat-lying lava flows, drainage may range from dendritic to indiscernible due to internal drainage through characteristic columnar jointing. Large-scale parallel drainage frequently occurs in areas where planar flow surfaces are slightly inclined. The formation of gullies varies widely depending on the origin and manner of emplacement of the extrusive igneous rock formation. Gentle, U-shaped gullies will form on well-developed cohesive soils, while V-shaped gullies form on more granular material, such as tuff.

(c) **Vegetation in Areas of Extrusive Rocks**. Young volcanic cones that have been recently active or have steep side slop are unlikely to develop much vegetation. Likewise, young lava flows located in arid or semiarid environments are usually barren due to a thin soil cover. However, in humid or tropical climates, extrusive igneous rock flows weather rapidly, forming a thick, clay-rich soil profile in a short period of time. Consequently, deciduous vegetation is a predominant feature in such areas.

(4) **Engineering Properties of Extrusive Igneous Rocks**. The engineering properties of extrusive igneous rocks vary widely. Basalt is a hard, tough, durable source of aggregate for macadam, paving, and concrete, but it is seldom used as a building stone because of its dark color. Felsite is also an excellent aggregate, except when used with portland cement. (Silica present in the felsite chemically reacts with the alkalis of portland cement to create a gel that will absorb water, causing the cement to expand and crack.) The engineering properties of pumice and scoria are not as desirable as those of basalt and felsite. Neither

Note: Contour interval: 100 feet
A: Volcanic cone
B: Valley glaciers
Mount Rainier is an inactive composite volcano, but the resistance of its lava flows allows it to retain its characteristic form.

Figure 1-9. Topographic map of Mount Rainier, Washington



Note: Contour interval: 50 feet
A: Isolated mesas and buttes
B: Lava flow sheets
Mature lava flow. Basaltic lava once extended over the area as a continuous sheet, but most of it has eroded away, leaving only isolated mesas.

Figure 1-10. Topographic map of Raton, New Mexico/Colorado

pumice nor scoria can be used for the construction of load-bearing structures; however, they can both be used as lightweight aggregate or as insulating material. In general, obsidian possesses relatively poor engineering properties; thus, it is not a good construction resource.

2. **Sedimentary Rocks**. Sedimentary rocks, the most common of the three major categories of rock types, comprise approximately 75 percent of the exposed surface of the earth. These abundant rocks are made up of consolidated particles that have either accumulated in place or have been brought in by a transporting agent, such as wind, water, or ice. The particles are initially deposited in horizontal layers, or beds; which can be used to distinguish sedimentary rocks from the normally massive and nonbedded igneous rocks previously discussed. Over time, the individual sedimentary particles become consolidated by compaction from overlying sediments, by cementation through deposition of mineral matter in available pore spaces, or by recrystallization of component minerals. Most sedimentary rocks are composed of particles derived from weathering and erosion of preexisting igneous, sedimentary, and metamorphic rocks. If this is the case, the resulting sedimentary rock is referred to as a clastic rock. On the other hand, if the sedimentary accumulation was derived from chemical or biological processes, the resulting rock is referred to as a chemical or biochemical sedimentary rock. The mode of origin, coupled with individual rock characteristics, is used to classify sedimentary rocks (see figure 1-11).

NOTE: Pyroclastic volcanic tuff, which was previously discussed as an extrusive igneous rock, is considered by some to be an elastic sedimentary rock.

Composition/Origin	Characteristics		Rock Type
Clastic	50 percent of grains larger than 2 millimeters	Rounded	Conglomerate
		Angular	Breccia
	Sand-sized grains; rock breaks around grains		Sandstone
	Clay and silt-sized particles; rock breaks into plates		Shale
Chemical or Biochemical	Reacts with 10 percent HCl; dense texture		Limestone
	Reacts with 10 percent HCl; loosely packed shell fragments		Coquina
	Reacts with 10 percent HCl only when powdered; dense texture		Dolomite
	Very hard, brittle; cuts glass		Chert
	At least 50 percent by weight and 70 percent by volume carbonaceous plant material		Coal

Figure 1-11. Classification of sedimentary rocks

a. **Clastic Sedimentary Rocks**. Clastic rocks are sedimentary rocks composed of broken fragments of preexisting igneous, sedimentary, and metamorphic rocks. Due to differences in source material and weathering processes, the size of the broken rock fragments varies greatly. This wide range of particle size serves as the basis for further subdivision of clastic rocks. Although there are numerous specific rock types in this category, only the four most important ones will be discussed in the following paragraphs.

(1) **Conglomerate**. Conglomerates are elastic rocks composed primarily of well-rounded, gravel-sized particles of any rock type with finer-grained materials filling the pore spaces between the granule, pebbles, cobbles, and boulders. These types of sedimentary rocks result from the cementation of unsorted material that may have been deposited by glaciers, rivers, lakes, or oceans. Conglomeritic rocks are generally limited in their lateral extent, but when present in sufficient quantity, they exhibit a light photo tone on aerial photographs. Wide variations in the composition, degree of cementation, and degree of weathering of the component particles make the engineering properties of conglomerate highly unpredictable; therefore, they should be avoided in construction.

(2) **Breccia**. Breccia is very similar to conglomerate in that it also consists mainly of gravel-sized particles with fine-grained material filling the interstitial spaces; however, in this case, the large fragments are angular instead of rounded. These types of localized deposits result from landslides, fault movement, and talus accumulations. When breccias are of sufficient extent to be identifiable on aerial photographs, they appear light-colored. Like conglomerates, breccias make poor construction materials due to their unpredictable engineering properties.

(3) **Sandstone**. Sandstones consist of cemented sand grains that may be either rounded or angular, depending on the distance over which the sand traveled before deposition. Sandstone deposited near the source area tends to be made up of angular, poorly sorted particles of relatively nonresistant material, such as feldspar and mica. On the other hand, sandstones that have been deposited a considerable distance from the source area are commonly composed of well-rounded, well-sorted particles of fairly resistant material, such as quartz. The photographic tones of sandstone are normally light due to their well-drained structure and light-colored component minerals; however, jointing may occasionally cause them to appear "scrabbled."

(a) **Relationship of Topography to Sandstone Rocks**.

- Landforms Developed in Areas of Sandstone. The resistivity of sandstone formations to weathering and erosion depends largely on the type and amount of cementing material present as well as on the environment in which the sandstone is located. Poorly cemented sandstones readily disintegrate, whereas well-cemented, or indurated, sandstones are very resistant. In fact, most sandstones are fairly resistant; therefore, in most cases, the main differences in landforms produced are due to difference in climate. In temperate or humid regions, sandstones form a bold topography with massive, steep-sided hills. Sandstone may also serve as the overlying caprock in these areas because of their high relative resistance to erosion as compared to other types of sedimentary rocks. In arid or semiarid environments, sandstones from the caprock of numerous plateaus and ridges separated by rugged, angular terrain. Sharp, vertical cliffs are also common. Joints are prevalent on sandstones of all regions, although they may not be distinguishable in temperate or humid regions where soil cover is thick.

- Drainage Developed on Sandstone Rock. Because sandstones are highly permeable, homogeneous rock types and medium- to coarse-textured dendritic drainage patterns are normally developed, except in areas where extensive jointing modifies the drainage pattern to that of rectangular or rectangular dendritic. Deep valleys form along the eroded joint patterns. There are generally very few gullies developed on sandstone terrain, again because of the high permeability and low surface runoff. Where present, gullies are V-shaped because of the granular, noncohesive nature of the particles.

- Vegetation in Areas of Sandstone Rock. In humid climates, sandstones heavily support the growth of natural vegetation. The vegetation tends to be uniform, with coniferous trees predominating. In arid climates, sandstone will not support large amounts of vegetation due to a shallow soil cover and extensive caprock exposure.

(b) **Engineering Properties of Sandstone**. The toughness, hardness, and durability of sandstones vary widely, depending on their composition and degree of cementation. Clean, compact, quartz-rich sandstones that are held together by silica cement are generally good material for all types of construction. Impure, poorly cemented varieties, on the other hand, should be avoided in most cases. For this reason, it is important to carefully select sandstones that are to be used in construction.

(4) **Shale**. Shale is a general term applied to all sedimentary rocks composed of consolidated silt and clay-sized particles. Whereas sandstones are normally lithified by the cementation of individual grains, cementing agents are usually unable to penetrate deposits of finer-grained material, such as silts and clays. Therefore, compaction of these materials under the weight of overlying sediment is the primary process responsible for the formation of shale. A distinctive characteristic of shales is their tendency to break along planes of weakness that lie parallel to the original bedding plane. This property is called fissility. Photographic tones of shales in humid areas are dull gray with some mottling due to variations in moisture and organic content. In arid regions, the tone is uniformly light and dull except for some occasional parallel banding. Shales are very extensive rock formations, covering over 50 percent of the earth's exposed land surface.

(a) **Relationship of Topography to Shale**.

- Landforms Developed in Areas of Shale. Because of its mode of formation (compaction rather than cementation), shale tends to crumble more easily than other types of sedimentary rocks in almost all environments. Consequently, these weak rocks are very susceptible to weathering and erosion in both humid and arid climates. In humid regions, low, rounded hills and valleys (sometimes referred to as “sag and swale” topography) are common. “Badlands”, a type of highly dissected topography characterized by rounded ridges and steep side slopes, are often formed on shale in arid climates.

- Drainage Developed on Shales. Because homogeneous shale are relatively impervious, large amounts of surface runoff are likely. This results in the formation of a medium- to fine-textured dendritic drainage pattern in areas underlain by such rocks. The thick layers of cohesive soil that rapidly develop over shales are conducive to the development of U-shaped or box-shaped gullies, depending on the relative percentages of clay and silt-sized

particles. A soil that is composed mainly of clay will typically exhibit steep-sided, U-shaped gullies, whereas one composed almost entirely of silt will exhibit box-shaped gullies.

- Vegetation in Areas of Shale. In humid areas, shales are either intensely cultivated or heavily forested. The cohesive nature of the soils that develop in such areas is favorable for the growth of deciduous trees.

(b) **Engineering Properties of Shale**. In most cases, blasting is not required for the excavation of shale; however, shales generally make very poor construction material due to their weakness and lack of durability. In addition, many shales have a tendency to swell upon prolonged contact with water, making them undesirable as foundations.

b. **Chemical or Biochemical Sedimentary Rocks**. Sedimentary rocks with textures composed of interlocking crystals that formed as minerals precipitated from solution are called chemical rocks. These rocks are subclassified based on mineral composition rather than on particle size. In addition, there are a few types of sedimentary rocks largely made up of the remains of plants and animals. These are the biochemical sedimentary rocks. Chemical and biochemical rocks are closely related. In fact, some rock types display characteristics of both groups. For this reason, the major rock types of each of the two groups will be discussed here under one heading.

(1) **Limestone**. Limestone is an example of a type of sedimentary rock that may occur as either a chemical or biochemical rock. Those formed by biochemical processes are the most important because they make up approximately 90 percent of all limestone deposits. Biochemical limestones form as water-dwelling organisms composed of calcareous shells and skeletons die and subsequently settle to the bottom of shallow lakes and seas. Chemically derived limestone deposits are formed when the concentration of calcium carbonate in the water exceeds its solubility level. In these cases, the calcium carbonate ($CaCO_3$) precipitates (separates) from solution and sinks to the floor of the body of water. Limestones vary in color depending on the amounts and types of impurities present. Most pure limestones are white or light gray, while impure varieties may range from gray to black. Limestone is easily identified, since it readily effervesces when placed in contact with a 10 percent solution of hydrochloric acid (HCl). The overall photo tone of limestone in humid regions is a relatively uniform light gray, but it may be interrupted by the occurrence of darker spots that indicate sinkholes (see Lesson 1.B.2.b.(1)(a)). This mottled tone may be continuous throughout a limestone formation, or it may be patchy, depending on the number, size, and location of sinkholes. In arid regions, limestone normally exhibits a uniform light tone. Limestone is the most abundant chemical/biochemical sedimentary rock, and it represents approximately 10 percent of all sedimentary rocks.

(a) **Relationship of Topography to Limestone Rocks**.

- Landforms Developed in Areas of Limestone. Because limestone is highly soluble, it is very susceptible to chemical weathering in both humid and temperate climates. Water, which percolates through joints and along bedding planes, dissolves the rock, forming subterranean void spaces known as caves and caverns. The unsupported roof of such void spaces may eventually collapse, forming a series of surface depressions called sinkholes. These sinkholes may develop over time, or they may be created catastrophically; they may consist of

small, shallow depressions, or they may be large enough to destroy a city block. Regions in which there is considerable evidence of the dissolution of carbonate rocks are said to exhibit karst topography. Figure 1-12 shows the topography of a karstic region.

An extreme form of karst topography, called tropical karat, is prominent in regions of very high rainfall. The single most distinctive feature of tropical karst is the haystack, a steep-sided, knobby remnant of a limestone formation. Figure 1-13, page 124, shows the topographic expression of numerous haystacks. In arid regions, limestone is just as resistant to erosion as sandstone and, like sandstone, it may form the caprock of ridges or plateaus.

- Drainage Developed on Limestone Rocks. In regions of karst topography, solution cavities within the limestone cause internal drainage; therefore, few established surface water systems are present in such regions. Those that are present generally follow the angular alignments of joints, resulting in rectangular dendritic drainage patterns. Areas of tropical karst display no surface drainage; the highly permeable bedrock ensures that all drainage is internal. In contrast, surface drainage is well-developed on limestones in arid climates where karat topography does not exist. In such areas, intermittent streams are arranged in a medium- to fine-textured, angular dendritic drainage pattern. A few sag and swale gullies are present in the karat topography of humid regions. Occasionally, short, white-fringed gullies occur around the sinkholes. There are no gullies formed in tropical regions. In arid regions, there are very few gullies because of the shallow residual soils formed over limestone terrane.

- Vegetation in Areas of Limestone Rock. Very fertile, cohesive, clay-rich residual soils form on limestones of humid environments. These conditions favor the growth of deciduous trees. In fact, orchards are frequently planted on limestones in temperate climates. Only a thin, weak soil develops in arid regions; consequently, vegetation is usually sparse.

(b) **Engineering Properties of Limestone**. In general, limestone is a tough, hard, durable rock that serves as a quality construction material for all purposes. However, some impure varieties of limestone contain abundant amounts of clay that adversely affect the toughness and durability of the rock. These limestones should be avoided when selecting material for construction.

(2) **Coquina**. This is a coarse biochemical sedimentary rock composed entirely of poorly cemented calcareous shells and shell fragments. This sedimentary rock type will readily effervesce when brought into contact with a 10 percent solution of HCl. Massive accumulations of shell fragments occur only in localized areas; therefore, coquina is very limited in lateral extent.

(3) **Dolomite**. Limestones often undergo chemical reactions following their deposition. For example, magnesium ions (Mg^{+2}) may partially replace the calcium ions (Ca^{+2}) present in the calcium carbonate. The result is a calcium-magnesium carbonate rock called dolomite ($CaMg(CO_3)_2$). The characteristics of dolomite are similar to the limestone from which it was derived, although dolomites are more resistant to weathering than their limestone counterparts. This is especially evident in humid or tropical climates where dolomites do not develop the karst topography associated with pure deposits of calcium carbonate. Whereas limestone readily effervesces when a drop of HCl is placed on its surface, dolomite will react with HCl only when it is in a powdered form.

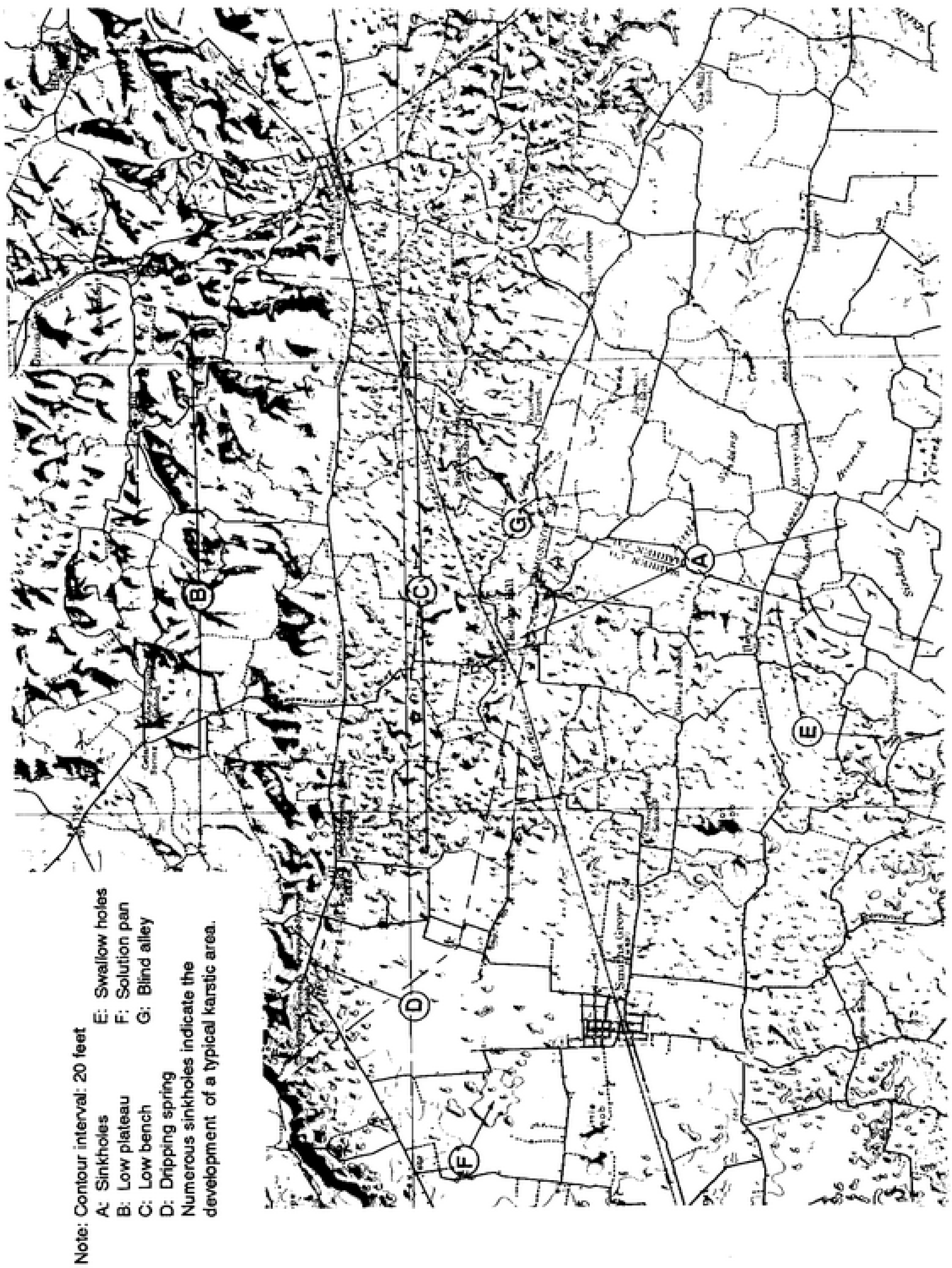


Figure 1-12. Topographic map of Mammouth Cave, Kentucky

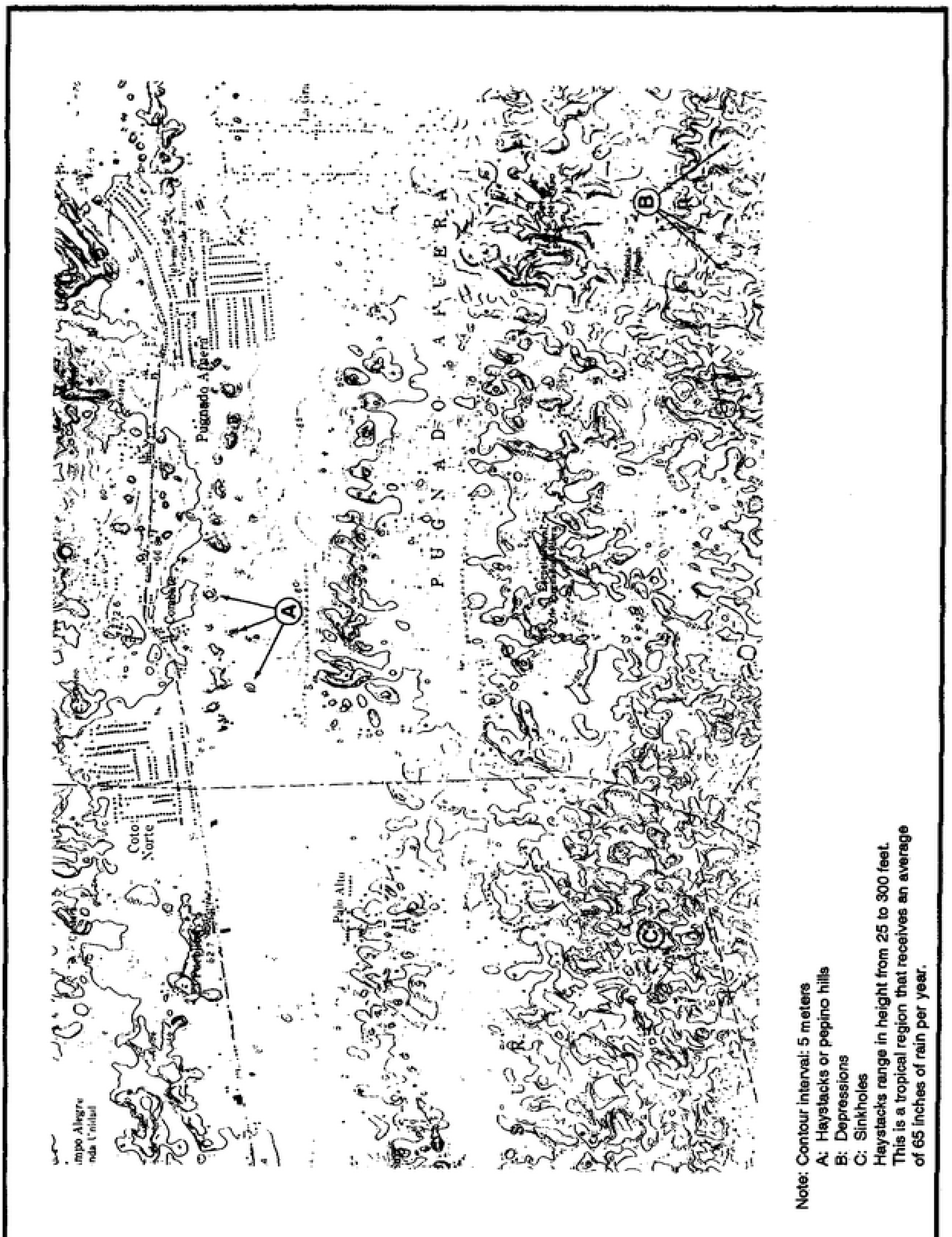


Figure 1-13. Topographic map of Manati, Puerto Rico

(4) **Chert**. Although the origin of chert is not well understood, it is believed to form from the precipitation of silicon dioide (SiO_2) from seawater. There are many impurities associated with silicon dioide, and their presence is reflected by the various colors of chert. Chert may occur as localized nodular concentrations or as massive beds, in which case they exhibit a light to medium gray homogeneous photo tone. The ability to recognize chert is important because of its very poor engineering characteristics. Due to the adverse reaction of chert with the alkalies of portland cement, this rock type should not be used as an aggregate for such cement.

(5) **Coal**. This is an organic sedimentary rock composed mainly of carbonaceous plant material. The first step in the formation of coal is the accumulation of vegetation at the bottom of a stagnant body of water. A lack of oxygen in this environment allows for only a partial decomposition of organic mater. The partially decomposed accumulation is known as peat, the lowest grade of coal. Eventually, the peat may become covered by sediments, such as sand, silt, and clay. As more and more sediments are deposited, the increase in pressure due to overlying weight forces water and organic gases out of the peat. In addition, the carbon content of the peat increases. As the process continues, the coal is progressively transformed from light brown, low-grade peat through mid-grade lignite and bituminous coal to jet-black, high-grade anthracite. Mid to high-grade varieties of coal are used extensively as fossil fuels.

c. **Interbedded Sedimentary Rocks**. As previously mentioned, sedimentary rocks are initially deposited in more or less horizontal layers called beds. Any disruption in the depositional process, such as a change in the velocity of the transporting medium or a change in the sediment source area, may result in interbedded sedimentary deposits. These deposits consist of a series of alternating layers of different rock types. For example, shales may be interbedded with sandstones and limestones. In fact, all sedimentary rocks are interbedded to various degrees, depending on their mode of formation. In many areas, interbedded sedimentary rocks still exist as they were deposited--in horizontal layers. These sedimentary sequences are called flat-lying interbedded sedimentary rocks. On the other hand, when the horizontal layers of interbedded sedimentary rocks are deformed by faulting or folding, the resulting assemblage is referred to as tilted or folded interbedded sedimentary rocks.

(1) **Flat-Lying Interbedded Sedimentary Rocks**. These rocks consist of alternating horizontal layers of two or more rock types. If the individual component layers are less than 25 feet thick, they are considered to be thin beds, whereas those that are greater than 25 feet thick are considered to be thick beds. Flat-lying interbedded sedimentary rocks are likely to show banding on aerial photographs. The banding, if present, will coincide with the contours of the land surface. In humid regions, thin-bedded sedimentary rocks normally develop deep residual soils that mask any banding that may exist. Therefore, an overall medium gray tone is predominant in these areas.

(a) **Relationship of Topography to Flat-Lying Interbedded Sedimentary Rocks**.

- Landforms Developed in Areas of Flat-Lying Interbedded Sedimentary Rocks. Interbedded sedimentary rocks composed of horizontal layers form hills of equal elevation in all environments. The variations in rock type exposed along the hillsides are responsible for the banded appearance of flat-lying interbedded sedimentary rocks on aerial photographs. If the interbedded sequences are composed of thick layers of rock, the side slopes of the hills will

be terraced, indicating differential weathering due to differences in rock type. Interbedded sedimentary rocks made up of thin horizontal layers are less likely to exhibit this stair-stepped topography, although very narrow terraces may follow the hillside contours in arid regions. In any case, the more resistant rock types, such as sandstone (and limestone in arid environments) comprise the caprock of the hills, while the weaker rocks, such as shale, occupy the lowlands. Figure 1-14 shows landforms developed on the flat-lying interbedded sedimentary rocks of the Colorado Plateau.

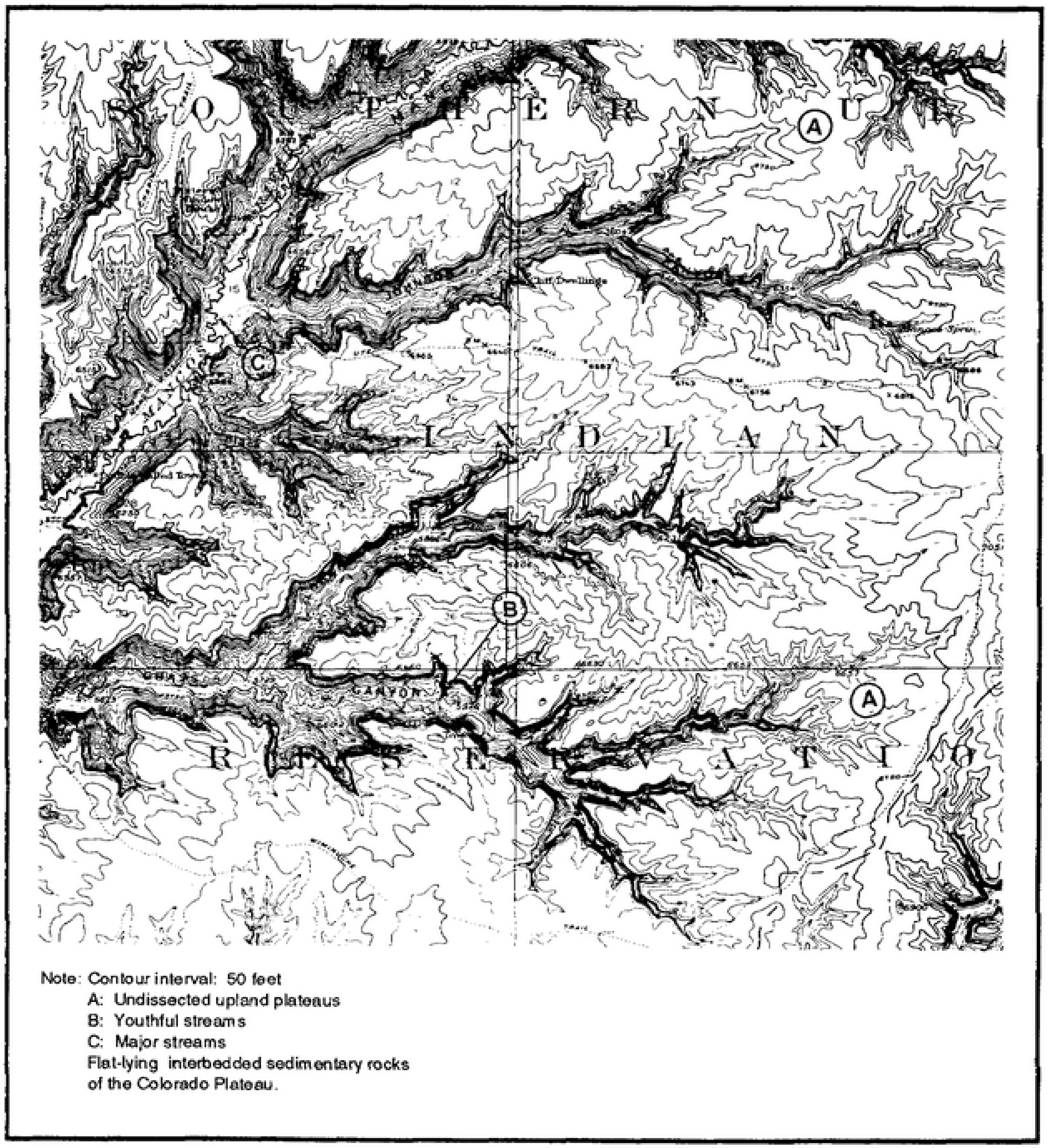


Figure 1-14. Topographic map of Soda Canyon, Colorado

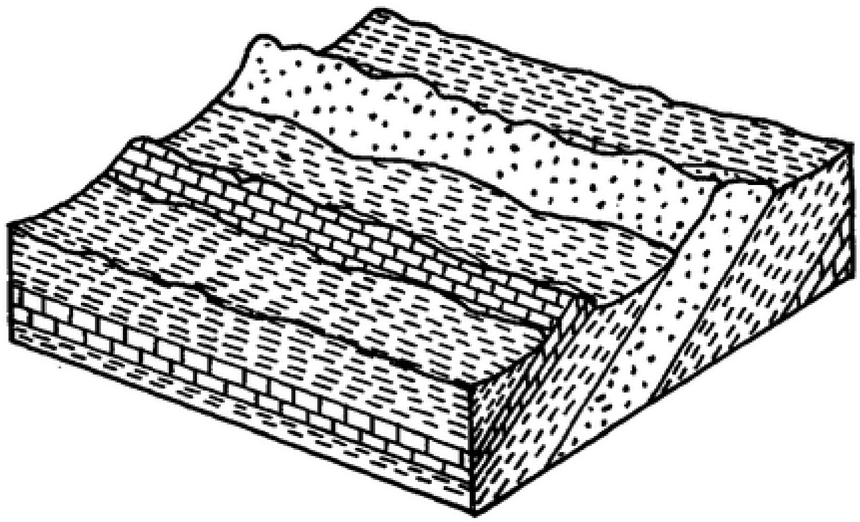
- Drainage Developed on Flat-Lying Interbedded Sedimentary Rocks. The horizontal uniformity of flat-lying interbedded rocks allows for the development of dendritic drainage patterns. The drainage tends to be controlled by the most resistant rock type, which is usually sandstone in humid climates and may be either sandstone or limestone in arid environments. Flat-lying sedimentary rocks that have been uniformly uplifted will have a deeply entrenched drainage system with exposed rock cliffs along the major watercourses (see figure 1-14). This is caused by the fracturing of sedimentary rock layers during the uplift, creating weak areas susceptible to stream erosion. In humid regions, the shapes of gullies formed in flat-lying interbedded sedimentary rock vary considerably but are usually of the sag-and-swale type, indicating cohesive soils. In arid regions, a lack of significant residual soil restricts the development of gullies.

- Vegetation in Areas of Flat-Lying Interbedded Sedimentary Rocks. In humid environments, the major rock type present in a sequence of flat-lying interbedded sedimentary rocks is generally responsible for the predominant vegetation type. Gentle slopes and valleys composed of shale are cultivated, whereas the steeper sandstone slopes remain forest-covered. In limestone and shale combinations, cultivated areas are found near major sources of water, such as sinkholes and drainage systems. If the component layers of the interbedded sequence are thick, then natural banding of vegetation may be visible along the hillslopes where alternating rock types are exposed. However, vegetational preferences in areas of thinly bedded layers are not easily distinguished. Interbedded sedimentary deposits in arid climates are generally rugged and have a thin soil cover. Therefore, most of these regions are barren except for some grass and scrub growth.

(b) **Engineering Properties of Flat-Lying Interbedded Sedimentary Rocks**. The engineering properties of interbedded rock sequences depend on the individual rock types present. In general, sandstones and limestones are suitable for most construction purposes, whereas shale is not. For more information regarding the specific engineering properties of each of these rock types, see Lesson 1.B.2.a.(3)(b) page 1-20; Lesson 1.B.2.b.(1)(b), page 1-22; and Lesson 1.B.2.a.(4) b), page 1-21, respectively.

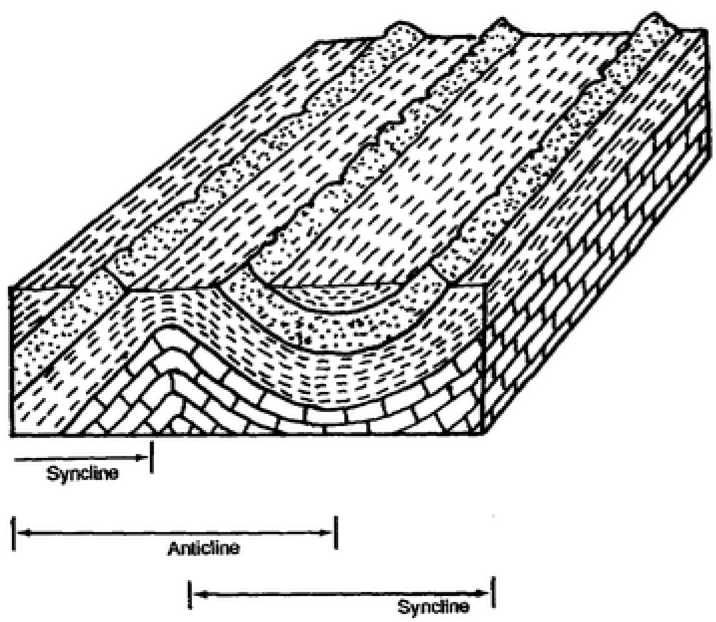
(2) **Tilted or Folded Interbedded Sedimentary Rocks**. Flat-lying interbedded sedimentary sequences are often subjected to processes, such as faulting or folding, that cause the beds to deviate from their original horizontal positions. When this occurs, the resulting sequences are referred to as tilted or folded interbedded sedimentary rocks. Figure 1-15, page 1-28, illustrates a sequence of tilted sedimentary rocks, and figure 1-16, page 1-28, depicts a folded sedimentary rock sequence.

Several structural forms may result from folding. Two of the more important ones, anticlines and synclines, are shown in figure 1-16, page 1-28. Anticlines are arches in the rock strata. As such, the beds of an anticline dip away from one another, and the oldest rocks are located in the center of the structure. Synclines, in contrast, are troughs in the rock strata. The beds of a syncline dip toward one another, and the youngest rocks are located in the center. Occasionally, anticlines or synclines are tilted so that they "plunge." Figure 1-17, page 1-29, shows an example of a plunging anticline. Tilted, folded, and deformed rock structures make up some of the world's largest mountain ranges.



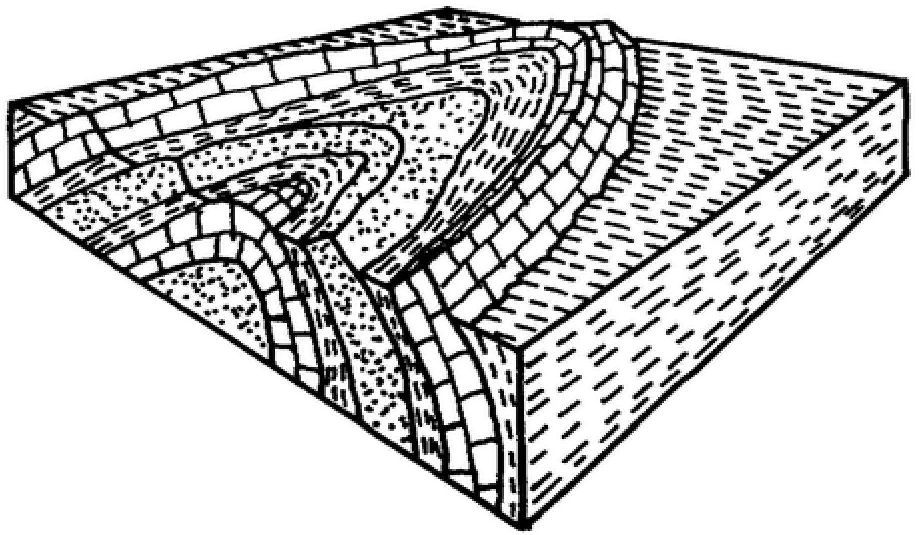
Note: Surface exposure shows parallel alignment of rock layers. Due to differential weathering, sandstones (dotted pattern) and possibly limestones (brickwork pattern), form topographic ridges, whereas shales (dashed pattern) form topographic valleys.

Figure 1-15. Tilted sedimentary rocks



Note: Surface exposure shows parallel alignment of rock layers. Due to differential weathering, sandstones (dotted pattern) form topographic ridges, while shales (dashed pattern) form topographic valleys.

Figure 1-16. Folded sedimentary rocks



Note: Surface exposure shows V-shaped alignment of rock layers. Due to differential weathering, sandstones (dotted pattern), and possible limestones (brickwork pattern), form topographic ridges, whereas shales (dashed pattern) form topgraphic valleys.

Figure 1-17. Plunging anticline

(a) **Relationship of Topography to Tilted or Folded Interbedded Sedimentary Rocks**.

- Landforms Developed in Areas of Tilted or Folded Interbedded Sedimentary Rocks. A series of tilted or nonplunging folds is represented on the surface by a parallel rock outcrop pattern, whereas a plunging fold is represented by a "zigzag" pattern. Because the various rock types exposed at the surface differ in their resistance to weathering, the topography in regions of tilted or folded rock takes on a saw-toothed appearance that is aligned in either a parallel or zigzag pattern respectively (see figures 1-15, 1-16, and 1-17). For example, in humid climates, the resistant sandstones dominate the topography with sharp parallel ridges and steep side slopes, while limestone form intermediate slopes, and shale make up the smooth, rounded lowland valleys. In arid environments, sandstone and limestone form resistant ridges, whereas shales form conical lowland hills.

- Drainage Developed in Areas of Tilted or Folded Interbedded Sedimentary Rock. The alternating ridges and valleys of tilted and folded interbedded sedimentary rock sequences control the trellis drainage pattern that is prevalent in such regions. The linear stream courses generally follow the lowlands composed of shale. In humid areas, sag-and-swale-type gullies are formed on both shale and limestone terrane; steeper-sided, V-shaped gullies may indicate underlying sandstone. In arid environments, residual soils are thin or nonexistent, so few, if any, gullies exist.

- Vegetation in Areas of Tilted or Folded Interbedded Sedimentary Rock. In humid regions, bands of varying types of vegetation may coincide with the various bands of exposed tilted or folded interbedded sedimentary rocks. Therefore, the vegetation may appear to have either a parallel or V-shaped pattern, depending on the extent of folding and/or faulting

within the area. Sandstones normally support heavy forest cover, while limestones are typically cultivated. Shales may be either forest-covered or cultivated. Vegetation in arid regions consist of a few scattered grasses and some sparse scrub growth in areas where water-bearing rocks outcrop at the surface.

(b) **Engineering Properties of Tilted and Folded Interbedded Sedimentary Rocks**. The engineering properties of interbedded rock sequences depend on the individual rock types present. In general, sandstones and limestones are suitable for most construction purposes, whereas shales are not. For more information regarding the specific engineering properties of each of these rock types, see Lessons 1.B.2.a.(3)(b), page 1-20; Lesson 1.B.2.b.(1)(b), page 1-22; and Lesson 1.B.2.a.(4)(b), page 1-21, respectively.

3. **Metamorphic Rocks**. Metamorphic rocks are formed from changes in the mineral composition and/or the physical character of preexisting igneous, sedimentary, or metamorphic rocks. These changes that are brought about by the application of heat, pressure, or chemically active fluids may occur in several situations. For example, during mountain-building processes, large rock formations are subjected to intense stress and high temperatures associated with large-scale deformation. This results in regional metamorphism, which is the mode of formation of most metamorphic rocks. Metamorphism may also take place when molten magma comes in contact with country rock. The solutions escaping from the magma may chemically alter the surrounding rock material. In addition, the country rock will most likely be "baked" under the extremely high temperatures. This type of metamorphism is known as contact metamorphism. Finally, metamorphism may occur along fault zones where the rocks are broken and distorted by pressure created from fault movement.

The metamorphic rock group is a small one; it makes up only about seven percent of the rocks exposed on the earth's surface. Metamorphic rocks are classified either foliated or nonfoliated (see figure 1-18). Foliated metamorphic rocks exhibit a series of parallel planar structures along which the rock flakes or splits into thin sheets. Nonfoliated rocks are massive and exhibit no structural features.

a. **Foliated Metamorphic Rocks**. The platy structure of foliated metamorphic rocks is the result of exposure to very high pressures, usually those encountered in regional metamorphism. Because regional metamorphism is the most widespread form of metamorphism, foliated rocks are the predominant metamorphic rock type. Within this category, three basic individual rock types are further classified based on their grain size (see figure 1-18).

(1) **Slate**. This is a very fine-grained, homogeneous rock formed from shale that has been subjected to low-grade regional metamorphism. Slate is highly foliated; therefore, it readily splits into thin plates. The color of slate may range from light gray to red or black, but the tone on aerial photography is normally a uniform light gray.

(a) **Relationship of Topography to Slate**.

- Landforms Developed in Areas of Slate. Slate weathers rather quickly, producing a very rugged, highly dissected topography with sharp parallel ridges and steep side slopes. Hilltops are relatively low but of approximately equal elevation.

Foliated			
Degree of Foliation	**Texture**	**Characteristics**	**Rock**
Excellent	Fine-grained	Splits easily into smooth sheets	Slate
Medium	Medium-grained	Rich in mica; splits easily	Schist
Poor	Coarse; banded	Streaked or banded	Gneiss

Nonfoliated		
Mineral Content	**Characteristics**	**Rock**
Chiefly quartz, some others	Hard; breaks across mineral grains	Quartzite
Chiefly calcite or dolomite	Granular; reacts with 10 percent HCl	Marble

Figure 1-18. Classification of metamorphic rocks

- Drainage Developed on Slate. The thin foliations so characteristic of the structure of slate provide planes of weakness that control the drainage system in areas underlain by this rock type. Therefore, slate tends to develop fine-textured, rectangular dendritic drainage patterns. Numerous short, parallel gullies are common, indicating relatively impermeable bedrock and large amounts of runoff.

- Vegetation in Areas of Slate. Vegetation on slate in humid environments consists mainly of forests. Due to the rugged topography and a lack of residual soil cover, there is little to no vegetation present in arid regions.

(b) **Engineering Properties of Slate**. Slate is a hard, dense homogeneous rock that is valuable as a roofing and tile material. Because of its poor crushed shape and low resistance to splitting, slate is unsuitable for aggregate or building stone; therefore, it is not considered to be a good construction resource. Because slate is often interbedded with anthracite coal, open-pit mining is common in these regions.

(2) **Schist**. This is a medium-grained rock formed from an intermediate degree of metamorphism of either igneous or sedimentary rocks. A moderate to high degree of foliation may be observed in schists, since they readily flake into thin sheets. This is because they are composed of alternating layers of different minerals, such as mica and feldspars. Schists in humid climates generally exhibit a uniform light gray photo tone on aerial photographs. Schists also display predominantly light tones in arid climates, although banding may also be evident. If banding does occur, the bands are parallel, but they do not follow topographic contours.

(a) **Relationship of Topography to Schist**.

- Landforms Developed in Areas of Schist. The landforms associated with schist in humid climates consist of smooth, rounded hills with steep side slopes. These hills are covered with deep soil profiles consisting primarily of well-drained, sandy silts and clays. In arid climates, there is a moderate, well-dissected relief with rugged surfaces and a thin soil cover.

- Drainage Developed on Schist. The foliated nature of schists is responsible for the development of a medium- to fine-textured, rectangular dendritic drainage pattern in both humid and arid climates. Many parallel, U-shaped gullies occur, attesting to the ease with which the sandy residual soils are eroded.

- Vegetation in Areas of Schist. The thick soils that develop over areas of schist in humid regions may support abundant vegetation. The tops of the rolling hills are normally cultivated, while the steeper side slopes remain forested. The vegetation on schist formations in arid regions is generally sparse, consisting of scattered grasses and scrub brush, with minor concentrations centered around areas of deeper soils or higher moisture.

(b) **Engineering Properties of Schist**. The tendency of schist to split into thin flakes makes it hazardous to excavate and undesirable as construction material. However, some higher-grade schists may be used for fills or base courses or as aggregate for portland cement.

(3) **Gneiss**. As heat and pressure steadily increase, schists begin to grade into gneiss, a rock representing the highest degree of regional metamorphism. Gneiss is a coarse-grained metamorphic rock made up of alternating layers of light and dark minerals that impart a banded appearance to hand specimens. Sometimes, banding is observable on a regional scale also, but it is often subdued. Planes of weakness along the banding allow the rock to be split into flat sheets, indicating that gneiss is a foliated metamorphic rock, although the foliation is not as well developed as it is in shale or schist. Where the ground surface is visible through the vegetation, a uniformly light photo tone is apparent on aerial photographs.

(a) **Relationship of Topography to Gneiss**.

- Landforms Developed in Areas of Gneiss. Landforms eroded from massive bodies of gneiss will generally consist of sharp, steep hills with parallel ridges, resulting from the differential weathering of the various minerals that make up the banded structure.

- Drainage Developed on Gneiss. The landforms produced by the differential weathering of this foliated rock control the drainage system that normally has a fine- to medium-textured, angular dendritic drainage pattern. Often, only a thin soil cover develops on gneissic terrane, but where soils are deep, U-shaped gullies will form, indicating that the underlying material is composed of a moderately cohesive sand-clay mixture.

- Vegetation in Areas of Gneiss. The thin residual soils that form on gneiss in all types of environments will usually support only a natural vegetative cover. In humid climates, these regions are forested; in arid climates, scrub and grass cover dominate, especially in valleys where soil depths are greater and more moisture is available.

(b) **Engineering Properties of Gneiss**. Gneiss is a reasonably hard, tough, and durable rock that serves as a good foundation and building stone. In addition, it breaks into bulky, irregular pieces, providing an excellent aggregate for most types of construction.

b. **Nonfoliated Metamorphic Rocks**. Nonfoliated metamorphic rocks are massive and show no evidence of planar foliation. They usually result from localized alteration processes, such as contact metamorphism or grinding action along fault planes; therefore, nonfoliated metamorphic rocks do not compose major landforms. Instead, they occur as small, scattered masses. Photographic interpretation of these rocks is difficult because of the small areal extent of single deposits. The two most common types of nonfoliated metamorphic rocks are quartzite and marble.

(1) **Quartzite**. This is a course-grained, light-colored metamorphic rock formed from the recrystallization, or cementation, of sandstones. High temperatures and pressures cause individual sand grains within the sandstone to become fused together, forming a homogeneous, nonfoliated structure. For this reason, quartzites break across the original sand grains, exposing a smooth, glassy surface. This hard, tough, nonfoliated metamorphic rock is the most resistant of all rock types; therefore, it forms topographically sharp ridges with shallow soil profiles. The physical properties of quartzite make it an excellent construction material, but the expense and difficulty of excavation and crushing make it costly to use.

(2) **Marble**. This is a compact, crystalline rock formed from the metamorphism of limestones or dolomites. The original calcite or dolomite grains are made to interlock with one another upon the addition of calcite into the structure during metamorphosis. Both the texture and color of marble vary considerably. The size of individual component grains may range from fine to coarse, and white bandings and mottles caused by impurities, such as iron oxides and organic matter, are common. Like limestone and dolomite, marble is easily recognized in the field by its characteristic effervescence when exposed to a 10 percent solution of HCl. The weathering characteristics, as well as the engineering properties of marble, are also similar to those of other carbonate rocks. Because of it softness, however, marble is rarely used as an aggregate for pavements on highways and airfields.

PART C - GEOLOGIC OVERLAYS

Once the types and characteristic of the rocks of a specific area have been identified, a geologic overlay may then be created. A geologic overlay is a transparent record or map of the spatial relationships and characteristics of rock types. The overlay may be superimposed on another graphic representation of the area, such as a map or aerial photograph, which serves as a frame of reference for the geology.

1. **Steps Involved in the Creation of a Geologic Overlay**.

There are several steps to be followed in creating a geologic overlay. The general procedures are as follows:

a. Assemble the available source materials pertaining to geology for the area of concern.

b. Examine the source materials to determine their accuracy and reliability.

c. Determine the types of rock present in the area from the assembled source material or through ground reconnaissance.

d. Record estimated or observed structural and engineering characteristics of the various rock types and any unconsolidated material that may be present, such as sand or gravel.

e. Rate both the structural and engineering characteristics of each unit. A rating of "A" should be assigned only where characteristics are of the highest quality, a rating of "B" should be assigned where the quality is somewhat lower, and a rating of "C" should be assigned when most of the characteristics are poor.

f. Delineate the boundaries and label the polygons of each unit, using a topographic map or remotely sensed image as a base.

g. Transfer the boundaries and labels to a transparent overlay material that has been registered to the topographic map or the remotely sensed image.

h. Add a legend to the margin of the overlay.

i. Edit the overlay to ensure neatness, accuracy, and completeness.

2. **Example of a Geologic Overlay**. Figure 1-19 is an example of a geologic overlay that was prepared by following the steps previously outlined. Figure 1-19(cont.), page 1-36, shows the supporting data tables for one of the units depicted in the sample overlay.

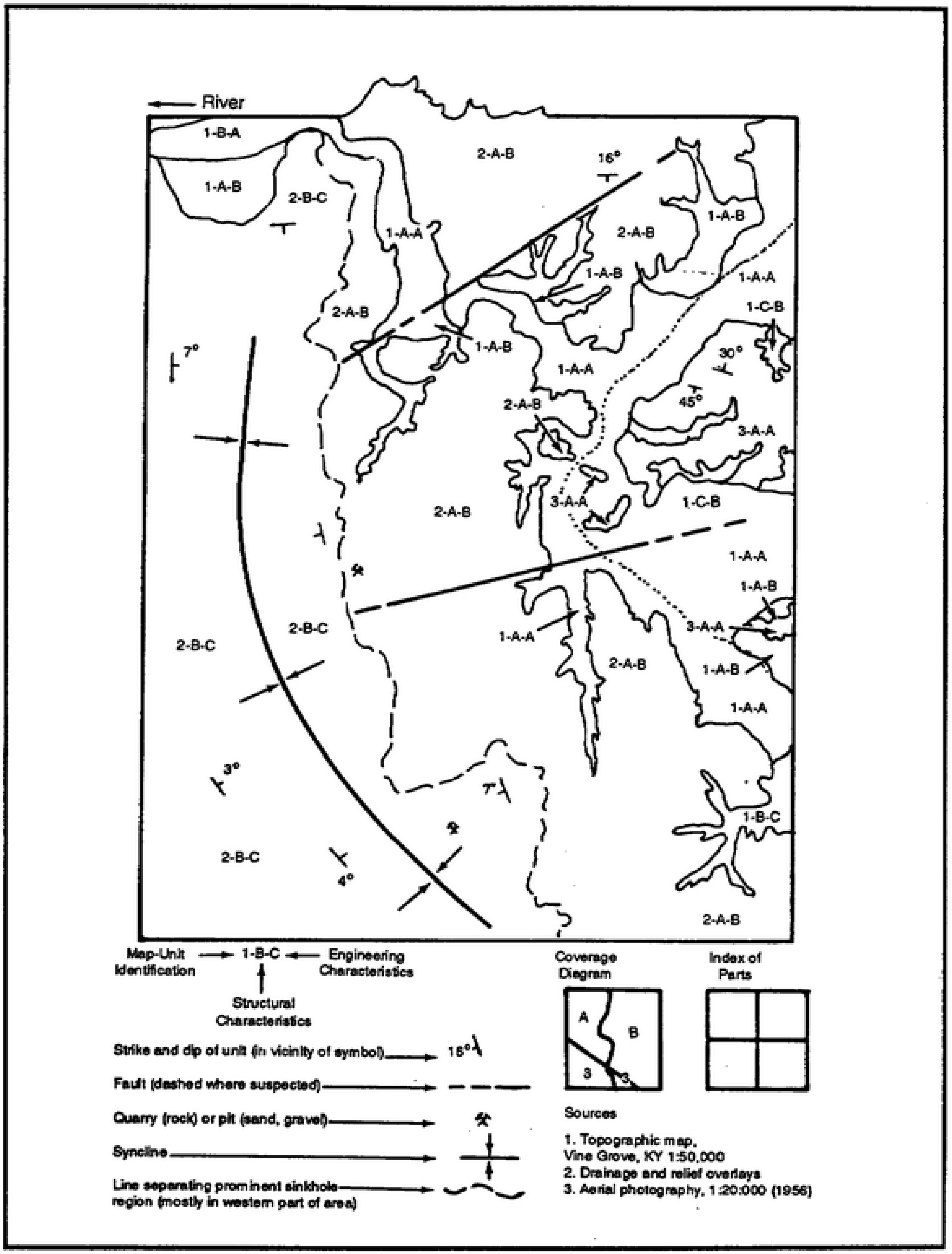


Figure 1-19. Sample of geologic overlay

Data Table					
Map Unit	**Rock Type**				
	Classification	**Composition**	**Grain Size**	**Color**	**Variations, Including Dissection, in Area**
1	Sedimentary	Shale	Fine to very fine		Forms round hills; steeper slopes on the north side; average relief is 500 meters above floodplains; drainage is dense on east slopes, with deep gulleys.

Data Table II					
Structural Characteristics					
Types of Layering	**Thickness**	**Strike/Dip**	**Joints/Faults**	**Seismic Aspects**	**Water Potential**
(?) Beds common in shale	(?)	(?) Contours suggest shale beds are dipping south	Drainage bends suggest east-west joints in shale beds	Good along north slopes where the rock is not deeply weathered	Poor except along the south base of shale hills where soil is deep

Rating: B

Data Table III					
Engineering Characteristics					
Weathering Aspects	**Swelling Data**	**Abrasion Data**	**Aggregate Suitability**	**Drill/Blast Aspects**	**Siting Suitability**
Deep soil (clay) is everywhere except on north slopes	(?) Shale usually swells	High losses are probable	Poor (no quarries on map); forms platy aggregate	Only deeply weathered shale along south slopes are rippable; light blasting	Good except on the base of slopes where high water table and low percolation rates in shale create foundation (water, slopes) problems

Rating: C

Note: Rate a unit as follows: "A" is given only when all the input is of the highest quality; "B" is given when all of the input is less than high quality; and "C" is given when all or most of the input is of poor quality. Data Table I shows that map unit 1 is classified as sedimentary, composed of shale, and forms round hills that are densely dissected on east slopes. Since the structural characteristics for map unit 1 are not particularly poor, it is given a rating of "B." However, since the engineering characteristics for map unit 1 are poor, it is given a rating of "C." This unit would appear on the factor map as "1BC."

Figure 1-19. Sample of geologic overlay (continued)

LESSON 1

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. There is only one correct answer for each item. When you complete the exercise, check your answer with the answer key that follows. If you answer any item incorrectly, study again that part of the lesson that contains the portion involved.

1. ______________________ are tabular bodies of intrusive igneous rock that cut across the structure of adjacent rocks.

2. Karst topography is typically developed on what specific rock type?

3. What type of rock is formed from the highest grade of regional metamorphism?

4. True or False. Marble is a metamorphic rock formed from the alteration of limestone.

5. What is the name given to a biochemical sedimentary rock consisting of at least 50 percent by weight and 70 percent by volume of carbonaceous material?

6. Which of the following is not a metamorphic rock?

   A. slate
   B. chert
   C. gneiss
   D. quartzite

7. What are the three major sources of geologic information?

8. Which rock type should never be used as an aggregate in portland cement because of its reactivity with alkalies?

9. What are pyroclastic rocks?

10. Name three distinctive types of volcanic cones.

LESSON 1

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback
1.	Dikes (page 1-7, paragraph a.(l)(b))
2.	Limestone (pages 1-21, 1-22, paragraph b.(l)(a))
3.	Gneiss (page 1-32, paragraph (3))
4.	True (page 1-33, paragraph (2))
5.	Coal (page 1-18, figure 1-11)
6.	B (page 1-18, figure 1-11; page 1- 30, paragraph (1); page 1-32, paragraph (3); page 1-33, paragraph (1))
7.	Maps (page 1-2, paragraph 1) Remotely sensed imagery (page 1-3, paragraph 2) Geologic/geographic literature (page 1-3, paragraph 3)
8.	Chert (page 1-25, paragraph (4))
9.	Pyroclastic rocks are composed of individual volcanic rock fragments that were explosively or aerially ejected from a volcano (page 1-6, paragraph 2; page 1-13, paragraph (d))
10.	Cinder cones (page 1-13, paragraph (3)(a)) Shield volcanoes (page 1-13, paragraph (3)(a)) Composite cones (page 1-13, paragraph (3)(a))

If you experienced any difficulty with any of the questions, review the appropriate sections before proceeding to Lesson 2.

LESSON 2

WEATHERING, EROSION, AND DEPOSITION

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn to identify the effects of weathering and erosion on geologic materials. You will also learn to recognize depositional features.

TERMINAL LEARNING OBJECTIVE:

ACTION: Identify the military importance of weathering and erosion of geologic materials and be able to recognize and describe depositional features.

CONDITION: You will be given information on weathering, erosion, and deposition.

STANDARD: Demonstrate competency of the skills and knowledge involved in identifying and interpreting the effects of weathering and erosion on geologic materials as well as recognizing and interpreting depositional features. This will be done according to FM 5-33 and TM 5-545.

REFERENCES: The material contained in this lesson was derived from the following publications: FM 5-33 and TM 5-545.

INTRODUCTION

Geologic materials that are exposed at the earth's surface are continually subjected to atmospheric processes that alter their physical or chemical state. This natural alteration of rock material is referred to as weathering, and the main product of it is unconsolidated material known as soil. The loose soil particles, in turn, can be easily carried away by water, wind, ice, or gravity. The transportation of weathered geologic material is called erosion, and the diagnostic topographic expressions that are left behind are called erosional features. Finally, when the velocity of the transporting medium is decreased to the point where it can no longer carry the unconsolidated material, the eroded particles are deposited, resulting in the creation of numerous types of depositional features. An understanding of weathering, erosion, and deposition is critical to engineers for several reasons. For example, many engineering operations are concerned with the characteristics of weathered rock which may differ considerably from those of their fresh counterparts. In addition, the ability to recognize erosional or depositional features can lead to an accurate estimation of the type of materials present.

PART A - WEATHERING

There are two broad categories of weathering-mechanical, or physical, weathering (disintegration) and chemical weathering (decomposition).

1. **Mechanical Weathering**. Mechanical weathering is the physical disintegration or fracturing of rock material with no regard for any chemical changes that may occur simultaneously. This type of weathering tends to predominate in arid environments and generally results in the production of relatively large, angular rock fragments (gravel-sized particles or larger) that are composed of the same material as the parent rock. There are several common natural processes that may be responsible for mechanical weathering.

a. **Freeze/Thaw Water Cycle**. When temperatures drop below 32 degrees Fahrenheit, any water that may be present in the pores or fractures of a rock is subject to freeing. Initial crystallization of water molecules takes place on the surface therefore, liquid water may still exist below a cap of frozen ice. If temperatures remain depressed, the confined water underlying the ice layer will eventually freeze, and as it freezes, its volume will expand by nine percent. This will exert a great amount of pressure on the surrounding rock. After several cycles of freezing followed by thawing and then by freezing once again, the rock may eventually break into angular fragments.

b. **Temperature Changes**. Daily and seasonal temperature changes are accompanied by the alternate heating and cooling of rock material. In general, rocks expand when heated and contract when cooled. However, if a rock is made up of several different minerals, it may experience differential expansion and contraction when exposed to cycles of alternate heating and cooling. This could result in a weakening of the rock to the point where it is finally fractured.

c. **Exfoliation**. Many of the rocks that are now exposed at the surface of the earth were, at one time, buried at great depths. The release of confining pressures brought about by the wearing away of overlying rock material may cause expansion of the exposed surface. The expansion is normally accompanied by concentric fracturing parallel to the land surface. The broken rock fragments eventually spall off, or exfoliate from, the main rock body, which then takes on the appearance of an onion.

d. **Abrasion**. The physical grinding of rock material may result in the formation of scratches or grooves on the rock surfaces. Crustal movements, like faulting and folding, as well as mass movements, such as rock slides and avalanches, impart this type of mechanical destruction in a very short time. Running water in the form of streams and rivers and ice in the form of glaciers can also act as agents of abrasion.

e. **Organic Destruction**. Significant amounts of mechanical weathering are caused by the actions of organisms. For example, the root systems of plants have the ability to penetrate and enlarge small rock fractures, and burrowing animals, such as earthworms and ants, are capable of extensive sediment disturbance. In addition, human activities also contribute to the rapid disintegration of rock material. Mining, quarrying, and excavating construction sites are only a few manifestations of the influence of man.

2. **Chemical Weathering**. Chemical weathering of geologic material involves the alteration of its atomic structure. There are several methods by which this alteration may take place; however, all require optimal temperatures and the presence of water. Consequently, chemical weathering predominates in warm, humid environments. Weathered products generally consist of very fine-grained (clay and silt) particles. Some of the more common means of chemical alteration are listed below.

a. **Oxidation**. Oxidation is the chemical union of a compound with oxygen. This type of reaction often occurs when iron-bearing compounds are, under moist conditions, exposed to atmospheric oxygen. The process, commonly known as rusting, transforms original green or gray metallic substances to fine-grained red, yellow, or brown soils.

b. **Hydration**. Hydration is the chemical addition of water to the structure of a mineral. When the minerals that comprise a rock are hydrated, there is a corresponding increase in the volume of the rock. The volumetric expansion causes a decrease in both the density and cohesiveness of the rock. Some minerals are much more likely than others to accept water into their structures; therefore, they are more susceptible to chemical decomposition.

c. **Hydrolysis**. Hydrolysis, like hydration, involves a chemical reaction between water and the minerals composing a rock. However, in this case, both the minerals and the water decompose and react to form new, less resistant compounds. Many competent silicate minerals are hydrolyzed to incompetent clays.

d. **Carbonation**. Carbonation refers to chemical processes in which carbon dioxide, contained either in the atmosphere or in carbonated waters, reacts with rocks composed of magnesium, sodium, or potassium ions to produce carbonates and bicarbonates. These types of rocks, in turn, are extremely soluble in water.

e. **Solution**. All surface water contains carbon dioxide derived from the atmosphere. A portion of the dissolved carbon dioxide reacts with the water to form a weak acidic solution called carbonic acid. Carbonic acid, in turn, readily dissolves carbonate rocks, such as limestones and dolomites. The dissolved ions are carried away in the acidic solution, sometimes leaving huge void spaces called caves. Solutioning is the type of weathering responsible for the development of karst topography discussed in Lesson 1.B.2.b(1)(a), page 1-21.

PART B - EROSION AND DEPOSITION

The unconsolidated materials formed from mechanical or chemical weathering may be transported, or eroded, from their place of origin and later deposited in another location, thereby forming the basis for new sedimentary rocks. Each transportation agent (water, wind, ice, and gravity) is capable of forming its own unique erosional as well as depositional features. These agents and their associated features are discussed below.

1. **Water**. There are numerous types of erosional and depositional features created by the action of water. For example, streams, freshwater lakes, and waves are all masses of water, and each one is associated with its own types of features.

a. **Running Water**. Streams and rivers, which are forms of running water, are referred to as fluvial systems. Of all the transportation agents, fluvial systems are the most effective and, consequently, the most important to engineers. Structures have been made totally useless after a relatively short time by stream deposits or even completely destroyed by stream erosion. From an engineering standpoint, no two rivers are exactly alike; therefore, each one requires complete investigation. However, there are some general erosional and depositional features common to all fluvial systems.

(1) **Erosional Features of Running Water**. Although there are numerous types of erosional features associated with fluvial systems, only those most likely to be encountered will be discussed here.

(a) **Gullies**. A gully is a ravinelike erosional feature that does not permanently contain water and cannot be crossed by a wheeled vehicle nor covered by a farmer's plowing. These types of erosional features form when surface runoff becomes channelized. As gullies evolve, they take on characteristic cross-sectional shapes that reflect the textural composition and cohesiveness of the underlying soils; therefore, the cross-sectional shape of a gully can be used as an important indicator of the soil type and thus the parent rock material. Four general gully types may be distinguished on the basis of the cross-sectional shape (see figure 2-1).

- Shallow, Rounded Gullies. Gullies that have developed on cohesive, relatively impermeable materials, such as clays or silty clays, tend to be smoothly rounded in cross section.

- U-Shaped Gullies. The cross-sectional shape of a gully developed on weakly cemented sandy clay soils resembles a “U.”

- Box-Shaped Gullies. Box-shaped gullies, or gullies containing nearly vertical sides with flat bottoms, form in areas underlain by silty soils.

- V-Shaped Gullies. Gullies formed in areas underlain by granular soils, such as gravel or sand, take on a characteristic “V” shape when viewed in cross section.

(b) **Stream and River Valleys**. The primary features of fluvial erosion are the easily recognizable valleys of streams and rivers. Collectively, the valleys make up the drainage pattern and affect the type of topography that will develop over an area. Several different types of drainage patterns are possible, depending on the type of underlying geologic material that is present. See figure 2-2, pages 2-6 and 2-7, for some of the more common types of drainage patterns and their associated geologic materials.

Information may be gleaned not only from the shape of the drainage system but also from its density, or texture. For example, any type of flat-lying, homogeneous sedimentary rock unit may display a dendritic or rectangular drainage pattern. The problem is to determine which specific type of sedimentary rock is represented. Sandstones, conglomerates, and other coarse-grained rock types are usually permeable; that is, most precipitation will percolate downward through the soil and underlying rock. Therefore, the amount of surface runoff will be minimal, and a relatively small number of streams will develop in a precise area. This sparse stream development is referred to as coarse-textured drainage (see figure 2-3, page 2-8).

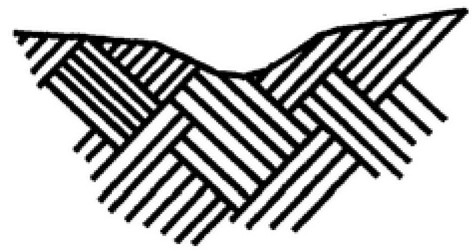
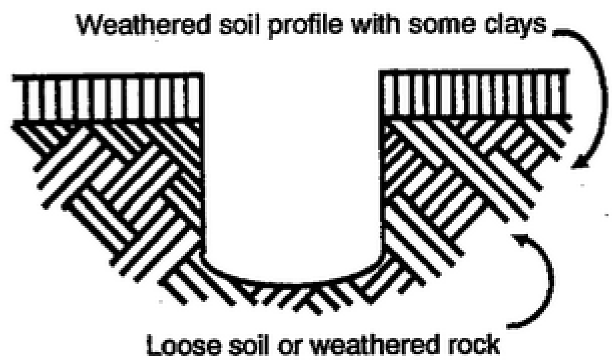
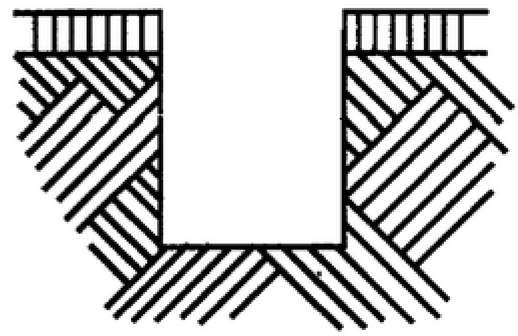
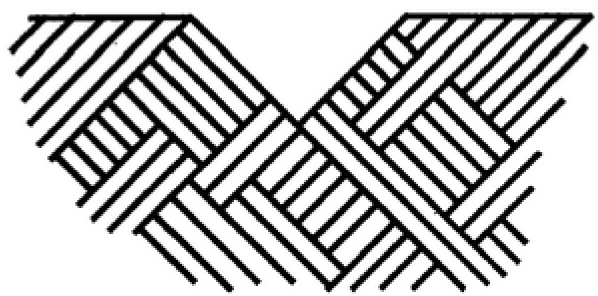
Underlying Material Type	Gully Cross Sections
Cohesive Clays and silty clays. (Usually found in lake-beds, marine terraces, and clay-shale areas.)	
Moderately Cohesive Weakly cemented sand-clays. (Occur in coastal plains and many bedrock areas.)	
Moderately Cohesive Silt. (Primarily found in loess and alluvial silt deposits. May also be found in fine volcanic-ash falls.)	
Noncohesive Granular materials. (Often found in terraces and outwash plains.)	

Figure 2-1. Gully forms associated with various types of geologic material

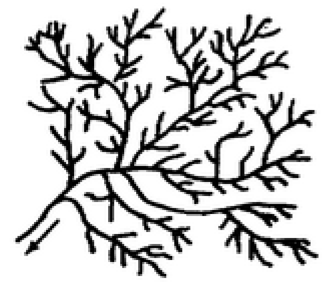
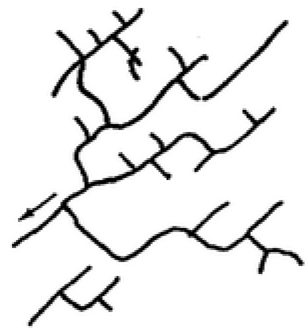
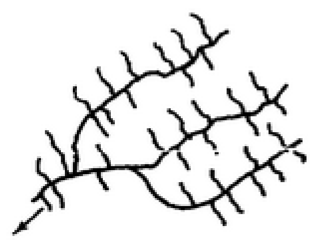
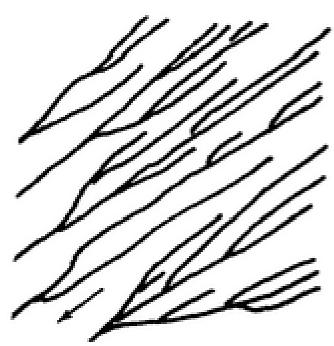
Drainage Pattern	Example
Dendritic This is a randomly developed, treelike pattern composed of branching tributaries and a main stream. It is the most common drainage pattern and is characteristic of essentially flat-lying and/or relatively homogeneous rocks and impervious soils.	
Rectangular This is sometimes called *rectangular dendritic* or *angular dendritic*. It is a modified version of the dendritic pattern, characterized by abrupt, close to 90-degree, changes in stream direction and distinct obtuse or acute angles of stream juncture. This pattern is usually caused by jointing or faulting of the underlying bedrock. It is usually associated with massive, intrusive igneous and metamorphic rocks.	
Trellis This is a modified version of the dendritic pattern. It forms in areas of folded rock strata. The main streams are parallel, following the lowlands, and they receive tributaries at right angles from adjacent ridges.	
Parallel This drainage pattern is characterized by major streams trending in the same direction. Tributaries usually join the main stream at approximately the same angles. Parallel streams are indicative of gently dipping beds or uniformly sloping topography. For example, sloping basalt flows and young coastal plains exhibit parallel drainage.	

Figure 2-2. Types of drainage patterns

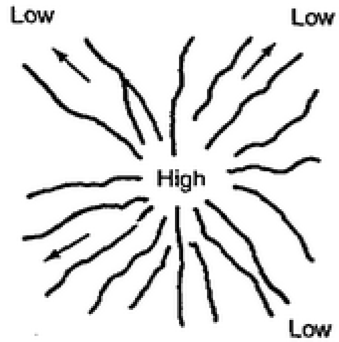
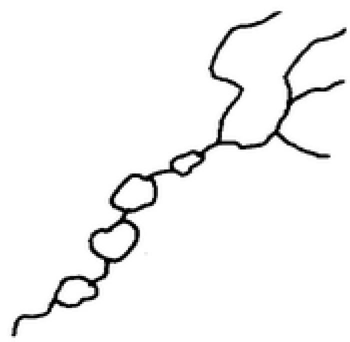
Drainage Pattern	Example
Radial Radial drainage is composed of streams radiating outward from a central peak, dome, or volcanic cone.	
Annular Primary streams develop in the concentric, circular joints surrounding an uplifted dome of sedimentary rocks. Fractures may also control the flow of tributaries, which are generally at right angles to the main stream.	
Internal There is very little surface expression displayed with internal drainage. Instead, there is a subterranean drainage system that is characterized by caves and sinkholes. Internal drainage is generally developed in areas underlain by soluble rocks, such as carbonates.	
Deranged This is a poorly defined drainage system resulting from a high water table and a flat or gently undulating topographic surface. These conditions are normally met in areas of glacial till plains.	

Figure 2-2. Types of drainage patterns (continued)

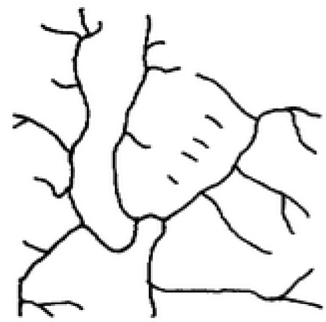
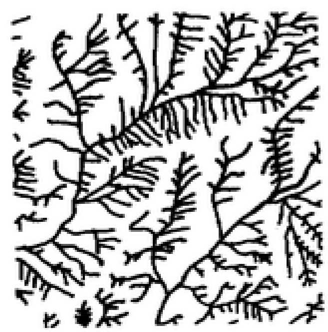
Drainage Pattern	Example
Coarse-Textured Coarse-textured drainage developed on sandstone.	
Fine-Textured Fine-textured drainage developed on shale.	

Figure 2-3. Comparison of coarse-textured and fine-textured drainage

Finer-grained rocks, such as shales, are fairly impermeable. Consequently, surface runoff is at a maximum, and erosion is often intense. The very dense drainage systems that result from this type of situation are called fine-textured drainage systems (see figure 2-3). In order to compare the densities of two or more drainage systems, those systems must be displayed at the same scale. Drainage textures are most frequently based on their appearances at scales of approximately 1:20,000.

(c) **Other Erosional Features of Fluvial Systems**. Streams rarely exhibit a straight-line flow; rather, they are gradually deflected from alignment by slight irregularities in their courses. The loops that form as a result of these deflections are called meanders, and the streams are called meandering streams. As channelized water flows downstream and rounds these loops or bends, pressure is concentrated against the channel wall on the outside of the curve, causing its erosion (deposition, which will be discussed later, occurs on the inside of the curve). As erosion progresses, the stream migrates, leaving abandoned channels and oxbow lakes in its wake. In addition to lateral erosion, the stream may also exhibit downward erosion. In these cases, old, level floodplains may be left high and dry while new ones are formed at lower elevations. Erosional slopes called alluvial terraces exist between the various levels of floodplains, producing a stair-step type topography. Figure 2-4 depicts several major erosional features associated with fluvial systems.

(d) **The Fluvial Cycle of Erosion**. There are three different stages that may be observed in the evolution of a stream-youth, maturity, and old age.

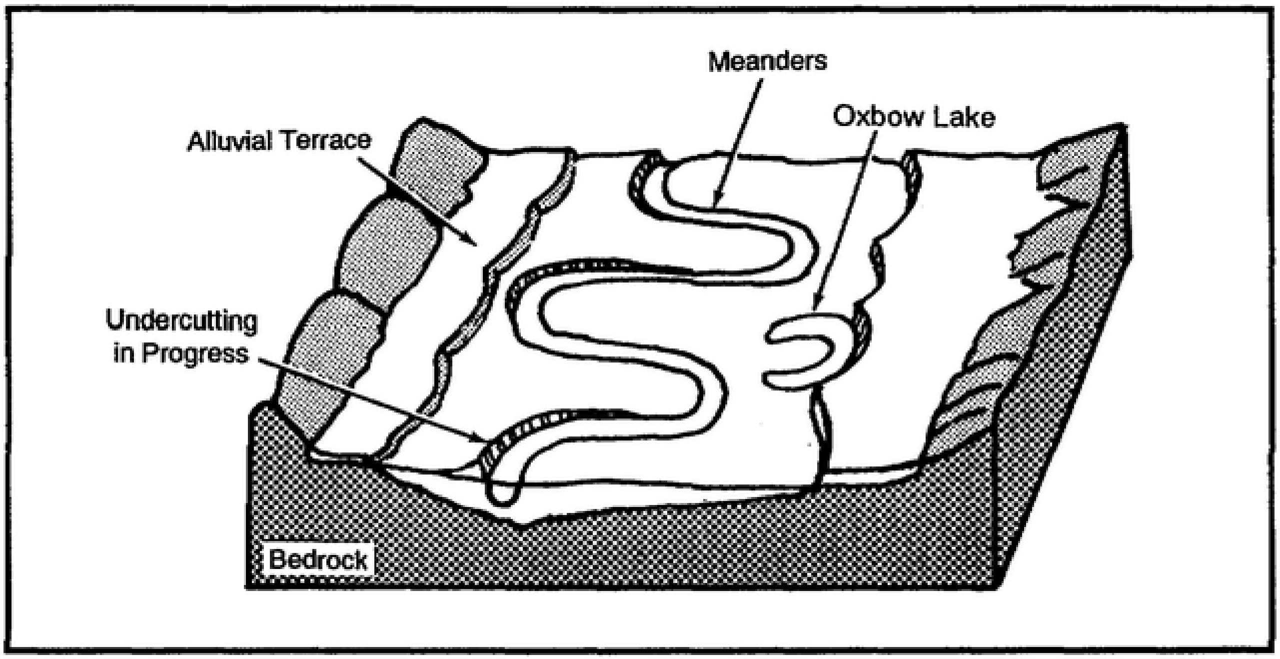


Figure 2-4. Erosional features of fluvial systems

- Youth. A youthful stream is one that is undergoing initial development; consequently, it has a steep, irregular gradient, few tributaries or meanders, and a narrow floodplain. In addition, most of the erosion takes place in a downward direction. Figure 2-5 illustrates the topography of an area containing a youthful stream.

- Maturity. As time progress and erosion continues, the stream gradient decreases. The number of course deflections, on the other hand, increases so that meanders begin to firm. Eventually, the degree of lateral erosion becomes equivalent to that of downward erosion. This intermediate stage of development is referred to as maturity. Figure 2-6 shows an example of a mature stream.

- Old Age. The final stage of stream evolution occurs when lateral erosion takes precedence over downcutting. These so-called old-age streams have very low gradient and wide floodplains. Table 2-1, page 2-12, lists the characteristics of each of the stages of stream evolution.

Occasionally, the land mass underlying an old-age stream is uplifted, and the stream is rejuvenated so that the stages are repeated in a cyclic manner. Therefore, the three stages of development are collectively referred to as the fluvial cycle of erosion.

(2) **Depositional Features of Running Water**. There are several factors that may cause the velocity of a sediment-laden stream or river to decrease. For example, the gradient may decrease, floodwaters may subside, or the water may evaporate or soak into underlying porous materials. In any case, as the velocity decreases, the sediments are deposited. The heaviest and coarsest materials are deposited first, while the lightest and finest particles remain in suspension for a longer period of time, traveling a greater distance from the source. The term alluvium is applied to all fluvial deposits with the exception of deltas, which occur in lakes or seas, and glaciofluvial deposits, which are generally referred to as outwash deposits.

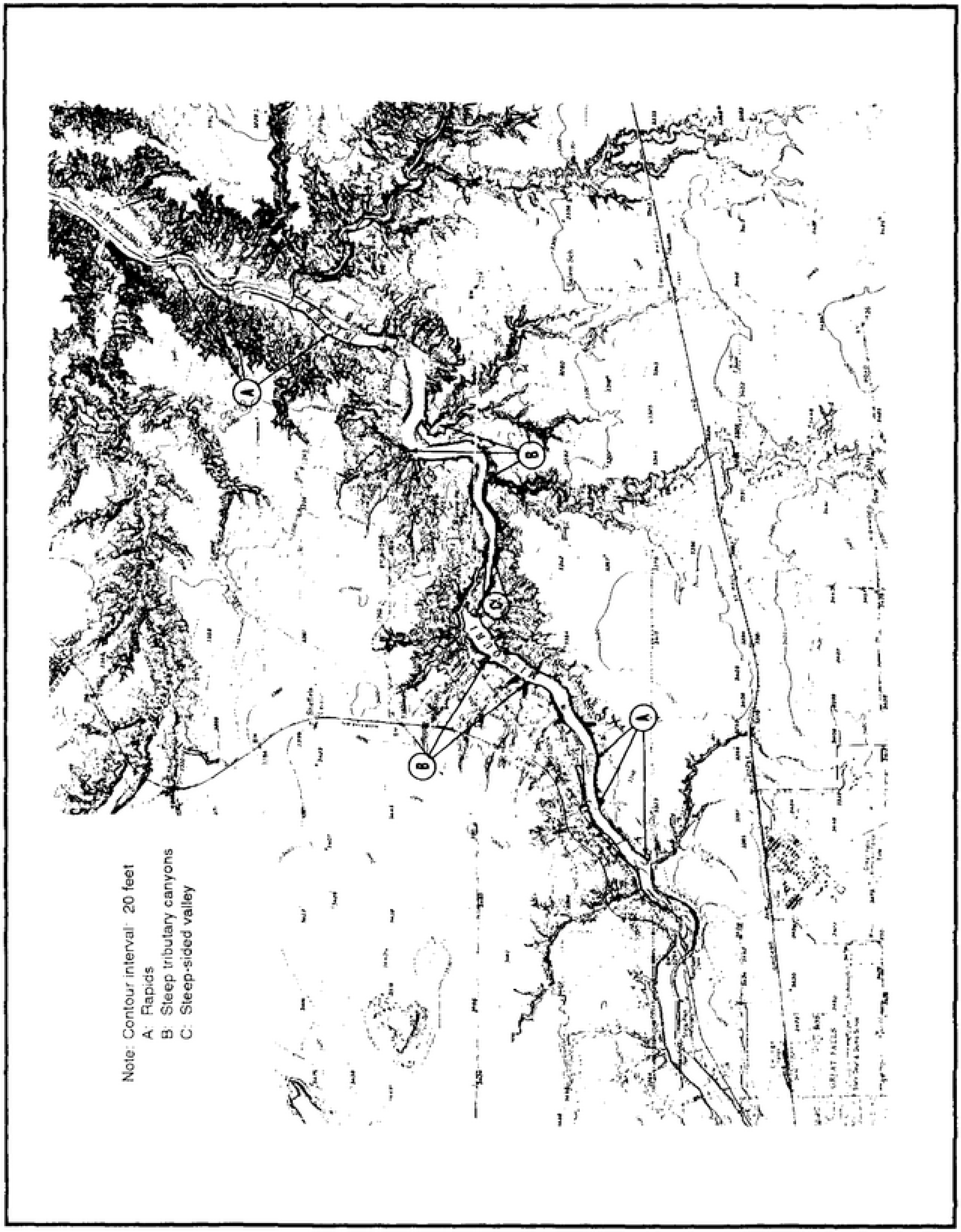


Figure 2-5. Topographic map of Portage, Montana

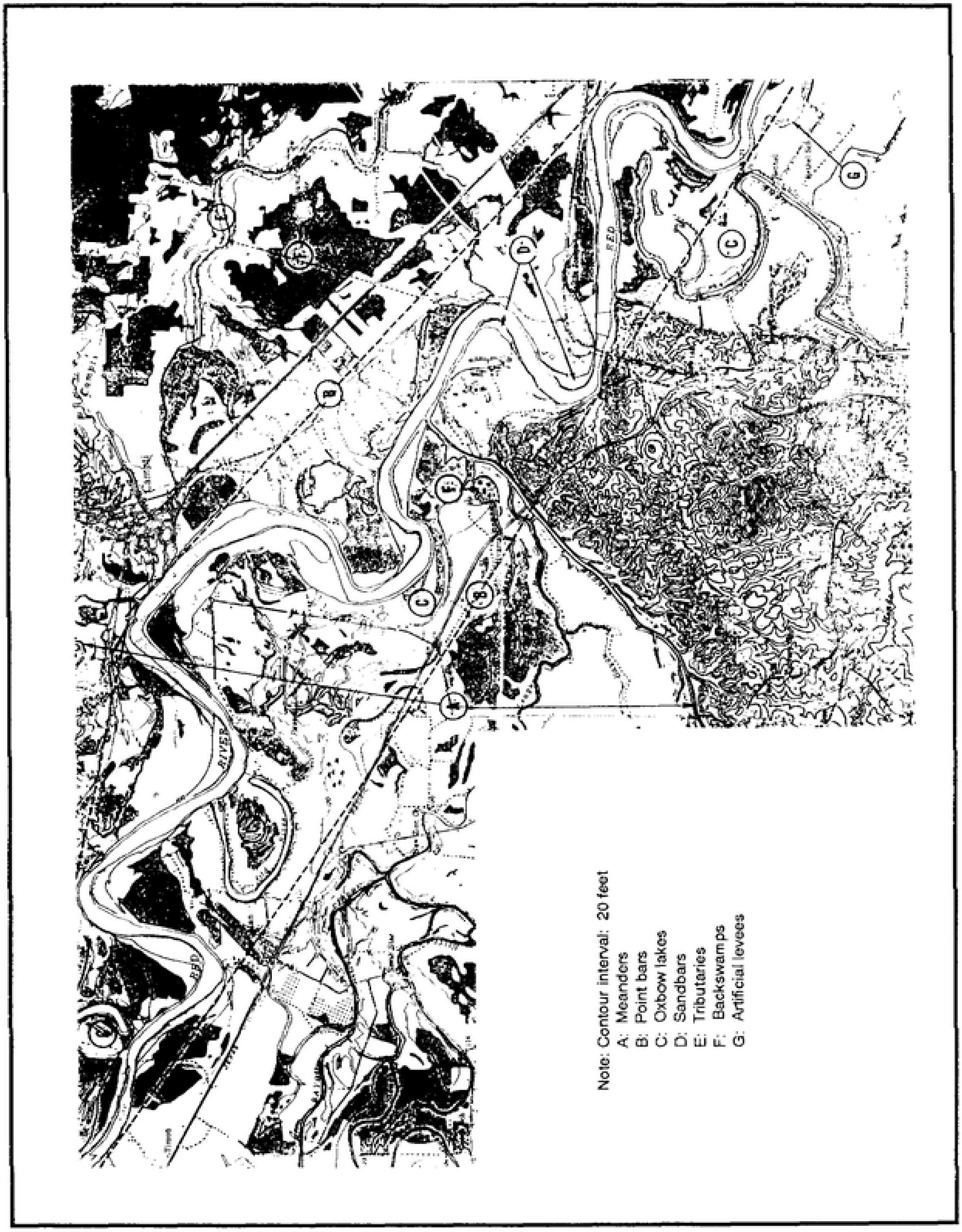


Figure 2-6. Topographic map of Campti, Louisiana

Table 2-1. Characteristics of the three stages of stream evolution

Characteristics	Youth	Maturity	Old Age
Gradient	Steep, irregular	Moderate, smooth	Low, smooth
Valley profile	Narrow, V-shaped	Broad, moderately U-shaped	Very broad
Valley depth	Deep	Deep, moderate, shallow	Shallow
Meanders	Absent	Common	Extremely common
Floodplain	Absent or small	Equals width of meander belt	Wider than width of meander belt
Natural levees	Absent	May be present	Abundant
Tributaries	Few, small	Many	Few, large
Velocity	High	Moderate	Sluggish
Waterfalls	Many	Few	None
Erosion	Downward cutting	Downward and lateral cutting equal	Lateral cutting
Deposition	Absent or transitory	Present, but partly transitory	Much and fairly permanent
Culture	Steep-walled valleys are barriers to roads and railroads	Flat valley floors are good transportation routes	Large rivers and nearby swamps are barriers
Summary of Regional Erosion Cycle			
Dissection	Partial	Complete	None
Divides	Broad, flat, high	Knife-edged	Low, broad, rounded
Valley development	Youthful to mature	Mostly mature	Old age
Number of streams	Few	Maximum	Few
Relief	Great	Maximum	Minimum

(a) **Alluvial Fans**. Where streams flow from step slopes onto bordering lowlands, the abrupt drop in gradient causes an associated loss in velocity. This results in the deposition of an alluvial fan, which is a fan-shaped feature with its apex located at the point where the stream emerges from the mountainous region. With further deposition, adjacent fans may grow and overlap one another, forming a continuous piedmont alluvial plain, such as the one shown in figure 2-7, page 2-14.

Alluvial fans are most commonly formed in arid or semiarid regions where streambeds are frequently dry except after torrential cloudbursts. For example, fans of enormous dimensions have developed along the margins of fault-block mountains in the western and southwestern United States.

(b) **Channel Deposits**. As previously mentioned, when water flows through a meander, erosion takes place along the channel wall on the outside of the curve, while deposition occurs on the inside of the curve. Therefore, the entire stream gradually migrates in the direction of the outer bank. As the stream migrates, the deposits along the inside of the curve grow laterally, forming a teardrop-shaped deposit known as a point bar (see figure 2-6, page 2-11). Point bar deposits are generally made up of relatively coarse-grained (sand- to gravel-sized) particles. During flood stages, the stream may cut across the meander, leaving crescent-shaped abandoned channels called oxbow lakes (see figure 2-6, page 2-11). Channel bars are similar to point bars in that they too form as a result of a decrease in stream velocity; however, they occur in the interior of the channel rather than along the edge, as in the case of a point bar. Channel bars normally contain relatively coarse-grained materials; it is unlikely that these types of deposits will be found where the sediment source is composed of clay, shale, or other fine-gained material. In instances where tributaries deliver a greater amount of sediment than the main stream can transport, a large number of channel bars are deposited. In some cases, the entire channel consists of a series of branching and reuniting streams flowing around and among the bars. These types of streams are known as braided streams (see figure 2-8, page 2-15).

Due to the generally coarse-grained nature of channel deposits, construction materials are commonly excavated from riverbeds. However, care should be taken in excavation because a borrow pit in the riverbed intercepts transported material and, at the same time, increases downstream scour. For this reason, excavations in the vicinity of structures, such as bridge piers, should be avoided. In general, it is best to locate borrow pits as far downstream from important river installations as possible.

(c) **Overbank Deposits**. Swiftly moving streams and rivers are capable of carrying large amounts of unconsolidated sedimentary material. However, when the stream level rises to the point where it overflows its banks (as in a flood), the velocity decreases. This initially causes the deposition of relatively large, heavy particles along the banks, followed by progressively smaller, lighter-weight particles at greater distances from the channel. The two long, narrow, coarse-grained ridges bordering the stream channel are called natural levees. Because of their composition, natural levees are often good sources of construction material, such as sand and gravel. The finer-grained (silt and clay) deposits form floodplains. In terms of aerial extent, floodplains are the primary depositional forms associated with fluvial systems. Figure 2-9, page 2-16, illustrates some common depositional features of running water.

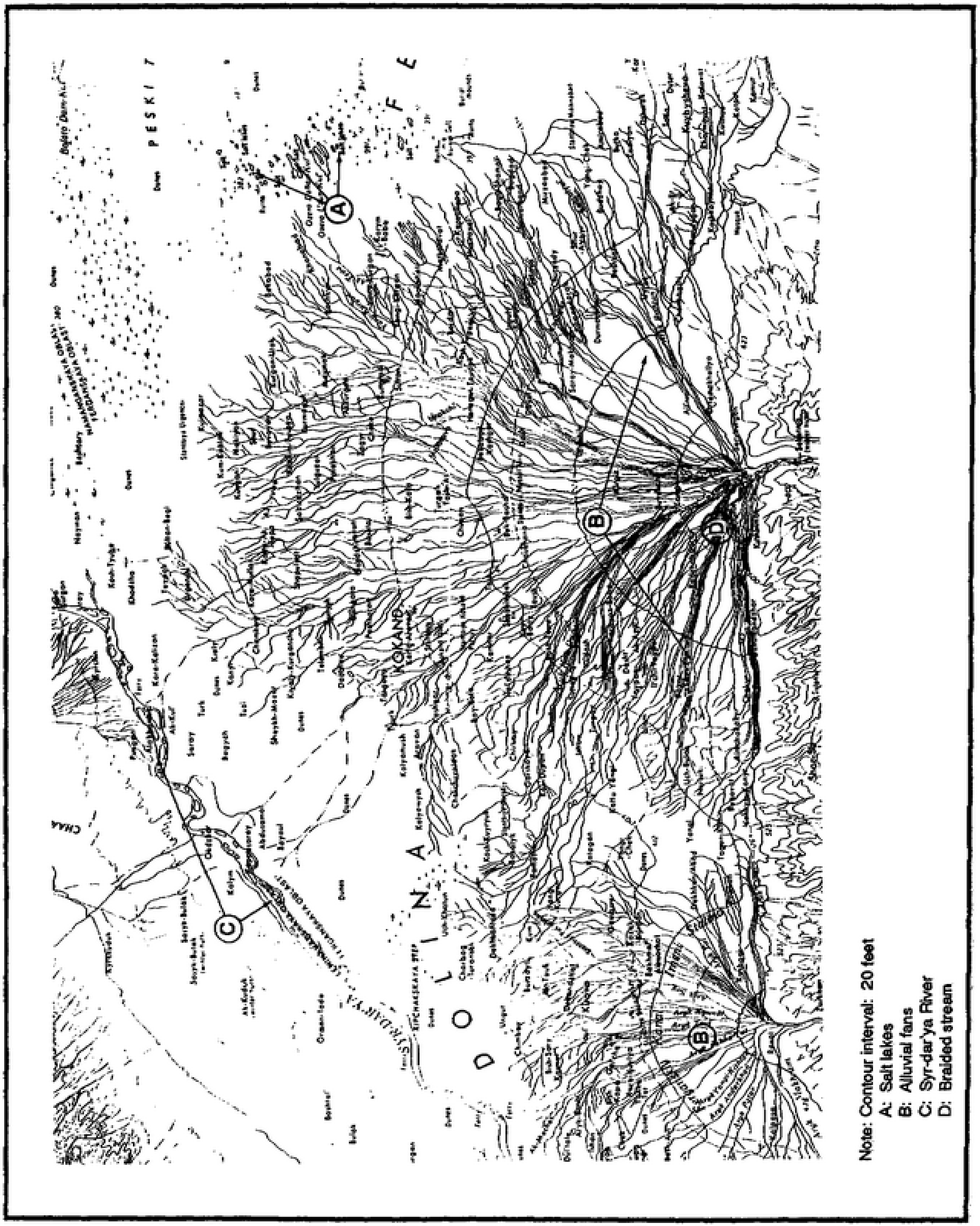


Figure 2-7. Topographic map of Kokand, Republic of Uzbekistan (Central Asian Republic, former Soviet Union)

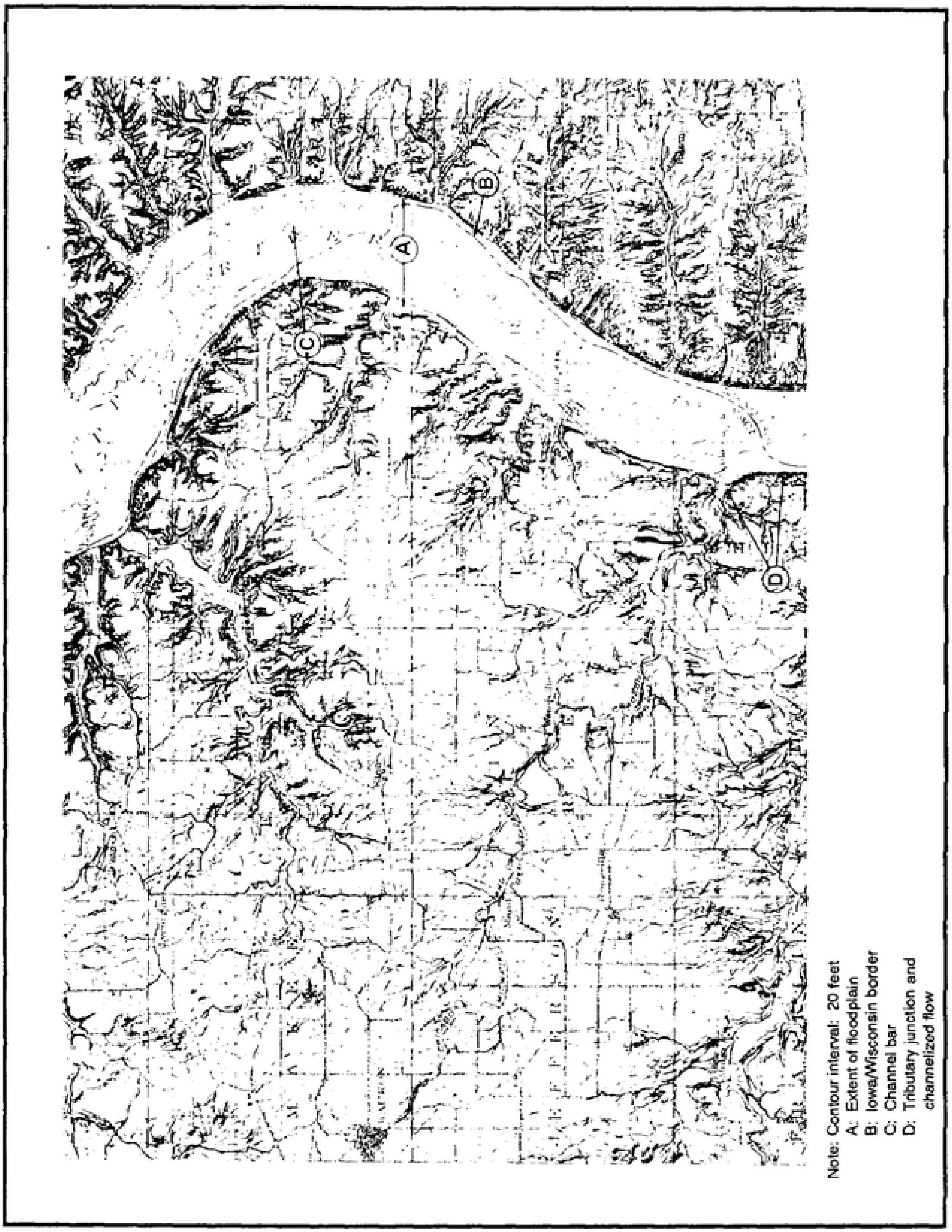


Figure 2-8. Topographic map of Waukdon, Iowa/Wisconsin

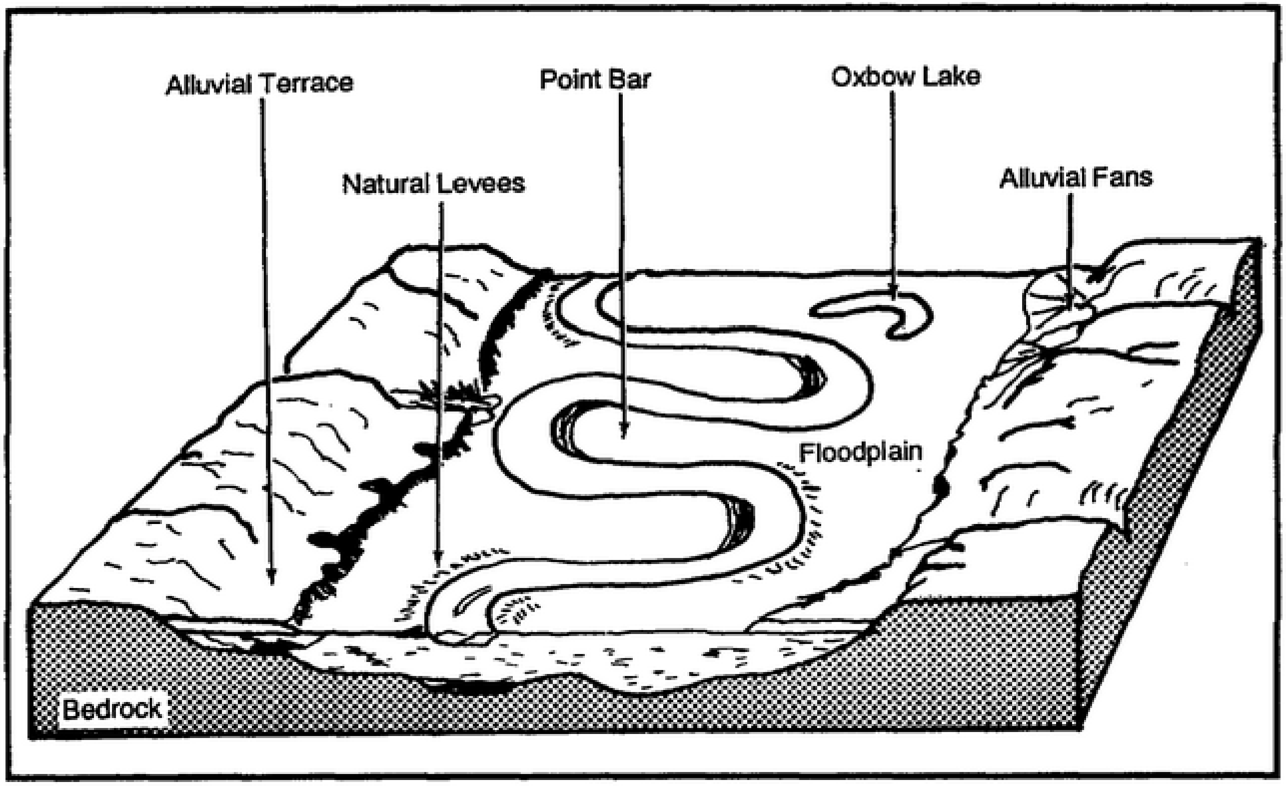


Figure 2-9. Depositional features of fluvial systems

(d) **Deltas**. When streams carrying suspended sediments enter the sea or another standing body of water, there is a considerable loss in flow velocity, causing a massive deposition of sediment. Naturally, the coarser particles, such as sand and gravel, settle from suspension first, while the finer material is carried farther out to sea. The result is the formation of a depositional feature called a delta. The shape of a delta varies depending on the relative influences of the river, waves, and tides.

River-dominated deltas take on a lobate appearance where the sediment supply is moderate and an elongate, or bird's-foot, appearance where there is a large sediment supply (see figure 2-10). A tide-dominated, or estuarine delta is composed of many linear distributaries that are aligned parallel to tidal flow and therefore perpendicular to the shore (see figure 2-10). Wave-dominated deltas tend to take on an arcuate shape (see figure 2-10). Figure 2-11 is an excellent example of an arcuate deltaic feature.

b. **Fresh Water**. Standing bodies of fresh water, such as lakes or ponds, are generally sites of deposition rather than erosion. Any deposit that owes its origin to a lake is referred to as a lacustrine deposit. Lacustrine deposits are usually made up of fine-grained material (silt or clay). In humid climates, successive growths of vegetation sometimes fill small lakes or ponds, creating the organic lacustrine deposits of freshwater marshes, swamps, and bogs. These deposits are characterized by flat topography, heavy vegetative growth, and highly compressible soils with a high moisture content. They also exhibit a lack of surface drainage. In arid or semiarid climates, dry lake-bed deposits, called playas or sebkhas, are common. These deposits are composed of evaporites, such as salt and gypsum, in addition to the fine-grained silts and clays. Playas and sebkhas can be recognized by their flat topography, lack of vegetation, and relationship to surrounding areas of higher elevation.

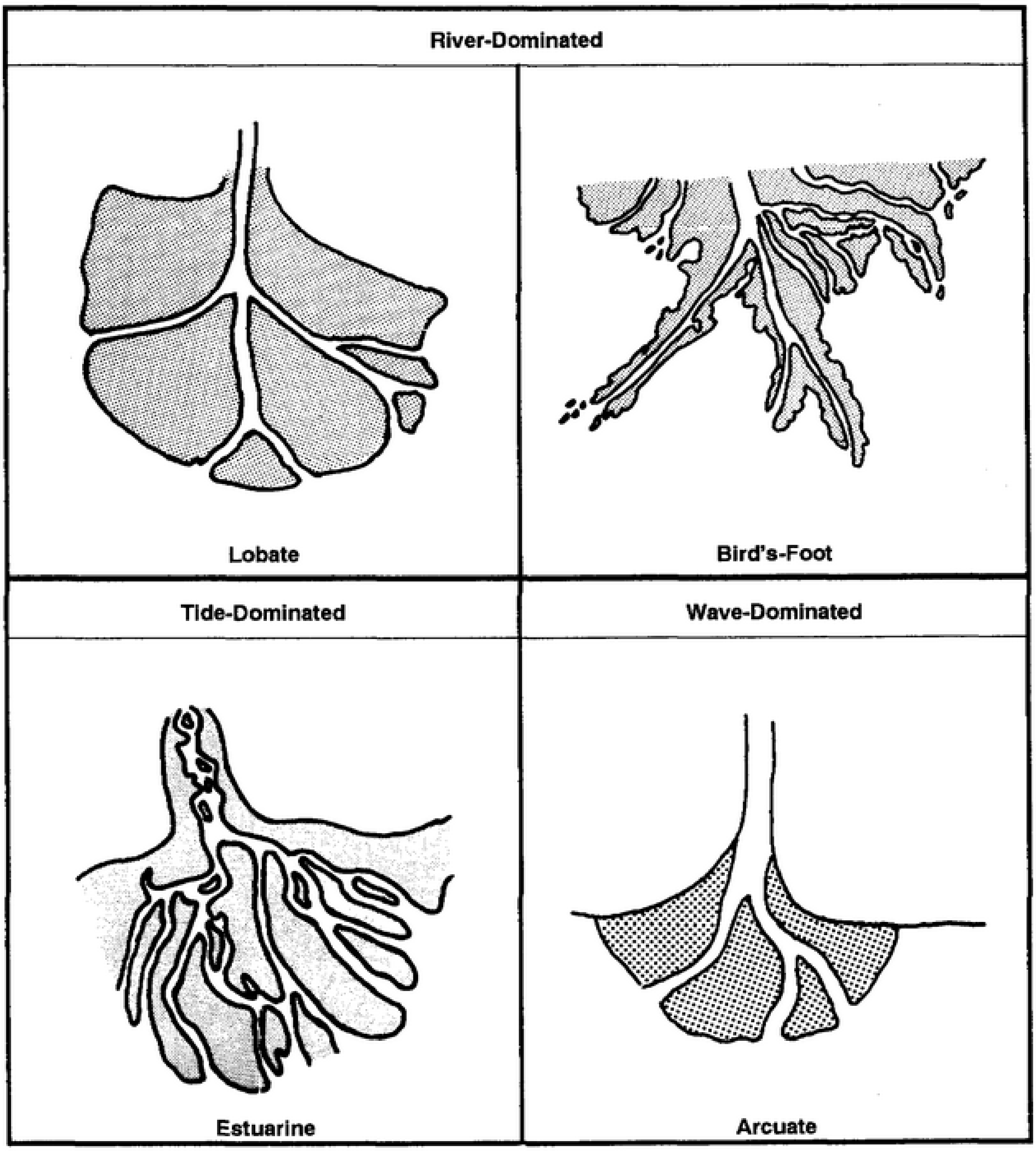


Figure 2-10. Delta types based on morphology

c. **Waves**. The passage of wind over an ocean causes an alternate rise and fall in the water surface, resulting in the formation of waves. When waves come into contact with the shoreline, they act upon existing geologic materials, creating either erosional or depositional features.

(1) **Erosional Features Created by Wave Action**. Erosion is the dominant geologic process that occurs where coasts are composed of exposed bedrock. As waves crash into the

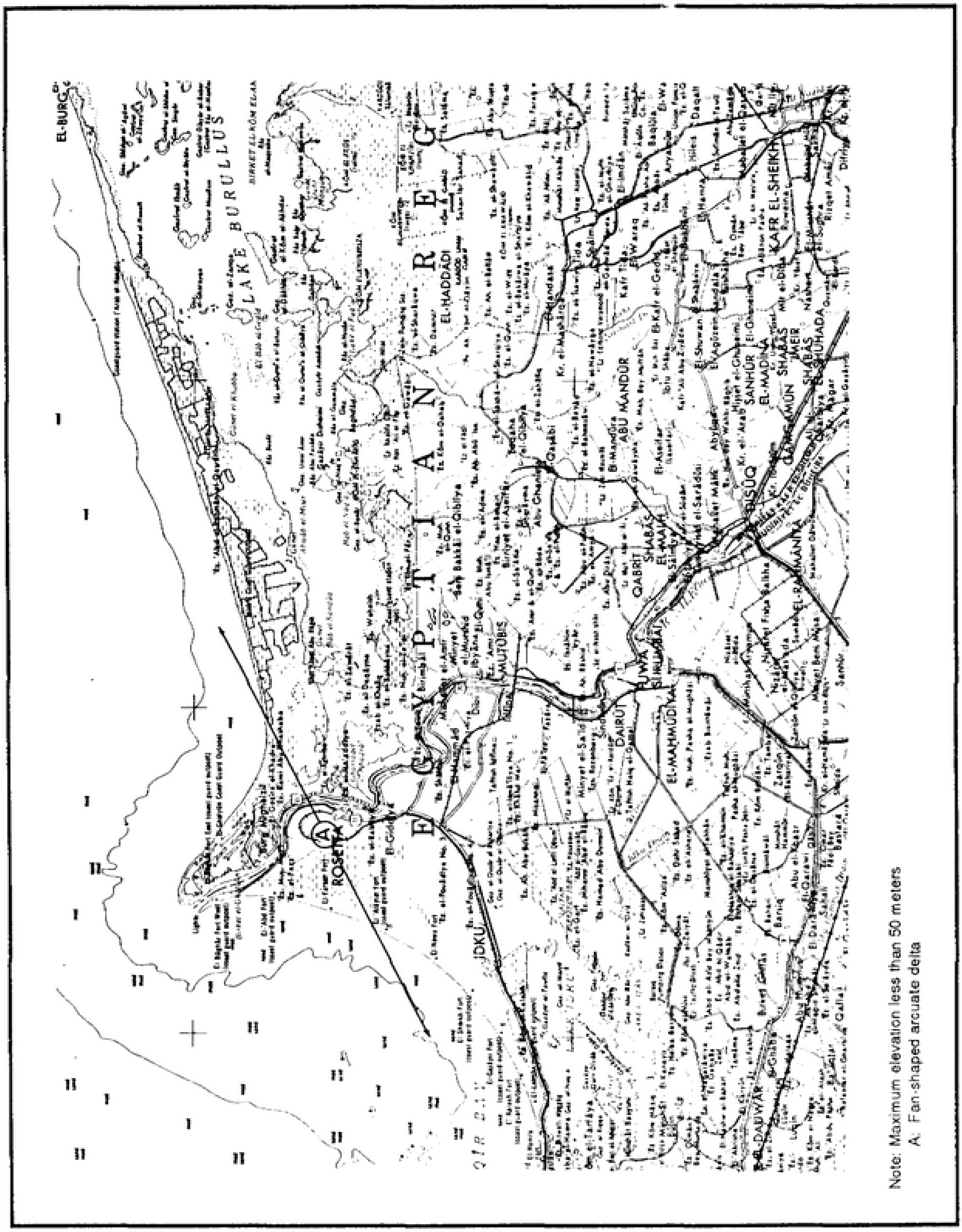


Figure 2-11. Topographic map of El-Mansura, Egyptian Region, United Arab Republic

rock, they carve various types of erosional features. The most important ones are discussed in the following paragraphs and illustrated in figure 2-12.

(a) **Wave-Cut Cliffs**. Wave-cut cliffs are seaward-facing cliffs that have been cut by wave action. Due to the erosive power of the waves, a concave notch is carved into the base of a rock mass, undermining its upper portion and causing it to crumble. The resulting rock fragments are then carried away by further wave action. Eventually, a steep-sided, gradually retreating cliff is created. Areas of relatively weak rock may exist on the cliff face, and these rocks are easily eroded, sometimes creating cavelike features called sea caves. In the event that a sea cave is enlarged to the point that it cuts completely through the cliff, a sea arch is formed.

(b) **Wave-Cut Benches**. A wave-cut bench is a bench, or terrace, cut from the bedrock at the base of a cliff. These benches slope gently toward the sea, and they gradually widen as their associated cliffs retreat landward. Most wave-cut benches are covered with rock fragments that have fallen from nearby cliffs but have not yet been carried away by subsequent wave action.

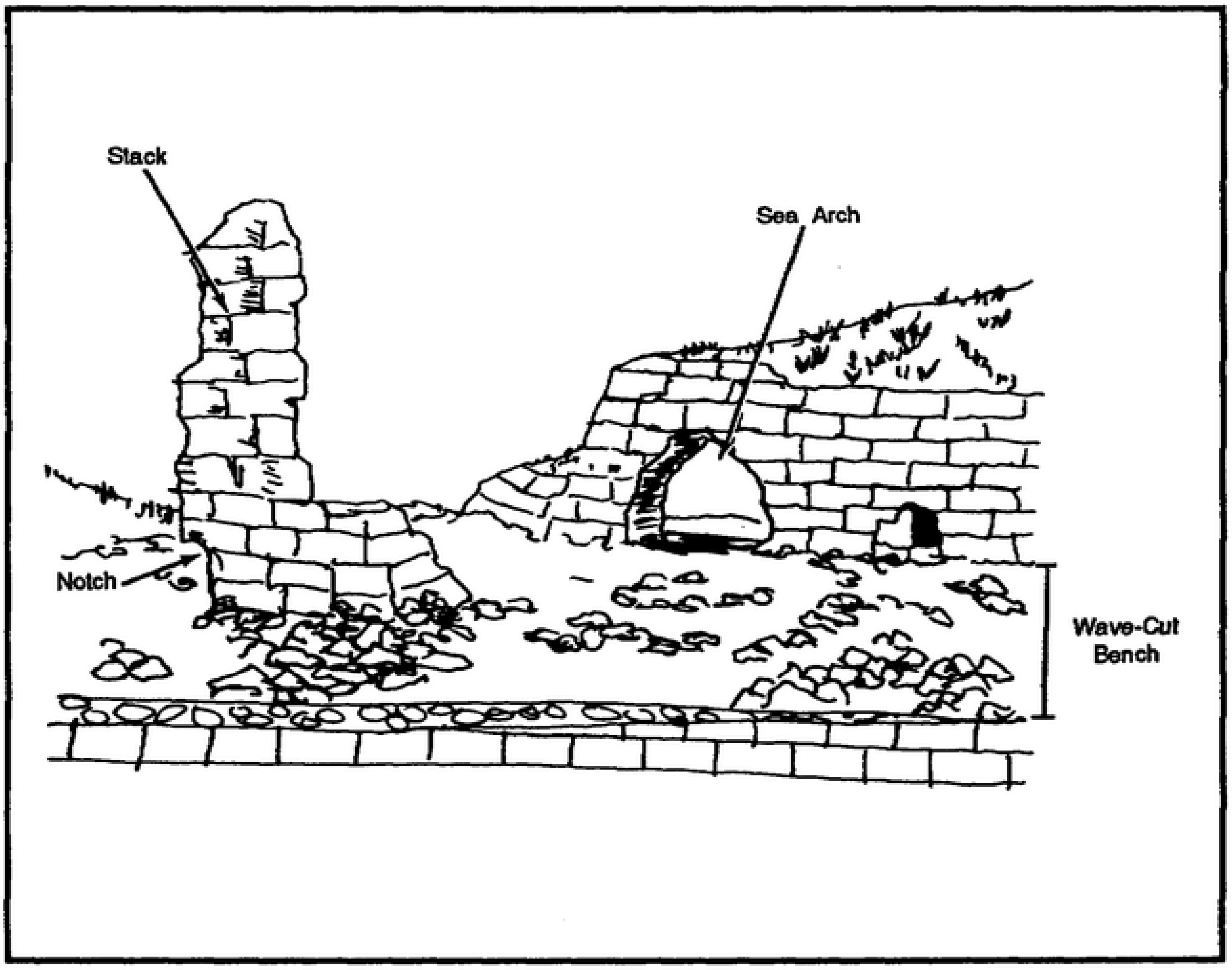


Figure 2-12. Erosional features of wave action

(c) **Stacks**. A stack is an isolated remnant of rock left standing on a wave-cut bench as the result of erosion by waves on all aide of a wave-cut cliff.

(2) **Depositional Features Created by Wave Action**. Where there is an abundant supply of unconsolidated material along the coast, the predominant geologic process is deposition. As waves approach the shore head-on, they sweep up loose sediments and carry them landward. The return flow of water washes much of the sediment back toward the sea. In addition, waves that meet the shore at an angle may create longshore currents, which transport material parallel to the shoreline. This complex reworking of coastal sediments is responsible for the development of several different types of depositional features (see figure 2-13).

(a) **Bars**. Bar is a generic term applied to any of a number of forms of elongate embankments of sand and gravel built on the sea floor by the action of waves and/or currents. These depositional features are further described by their positions in relationship to other coastal features. For example, a baymouth bar is a bar that extends partially or entirely across the mouth of a bay. A crescent bar is a crescentic sand or gravel ridge that forms between two promontories, or headlands. These types of bars are formed by the flow of seawater into an inlet or bay; consequently, the curved outline of a crescent bar is concave toward the ocean. A cuspate bar is a pointed bar with a tip that projects seaward. These bars are formed where there are conflicting shore currents. A special type of bar, known as an offshore bar or barrier island, is a sand and gravel ridge that lies offshore and is isolated from the mainland. Barrier islands commonly contain dunes, vegetated zones, and swampy terraces on the lagoonside of the island.

(b) **Tombolos**. Tombolos are ridges of sand or gravel that have been deposited in such a way that they connect one island to another or an island to the mainland.

(c) **Spits**. Elongate ridges of sand and gravel that project from the land to the sea are called spits. Most spits are simply extensions of bars, and they are built as longshore currents deposit sediment in areas where the water suddenly deepens, such as at the mouth of a bay.

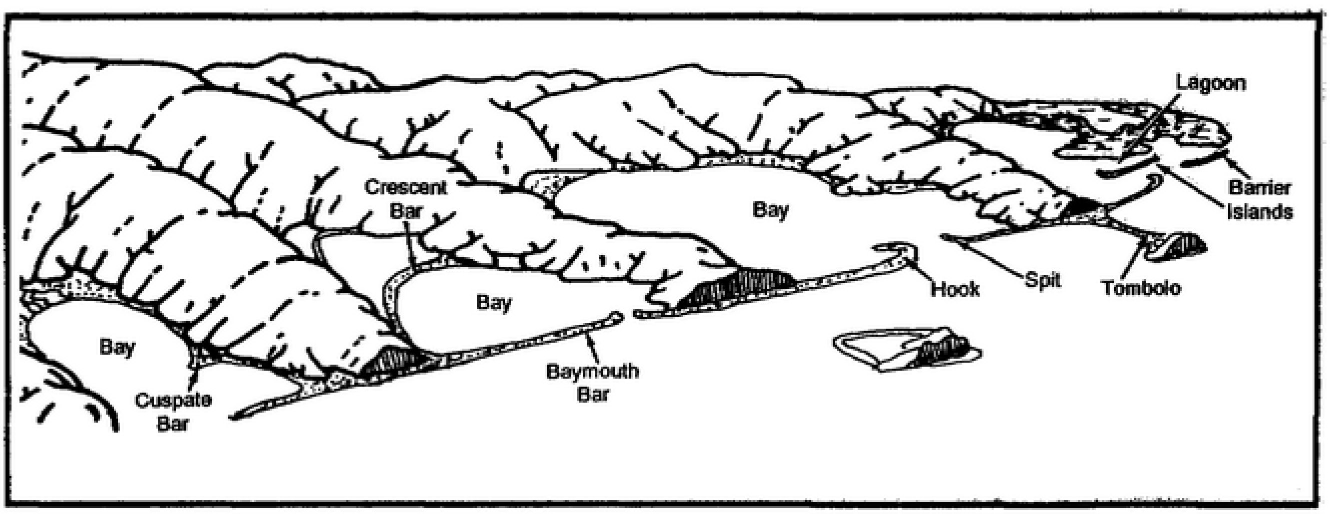


Figure 2-13. Depositional features of wave action

(d) **Hooks**. A hook, or recurved spit, is a spit with its tip turned towards the shore due to a deflection of the current that built it or to the opposing actions of two or more currents.

2. **Wind**. Although wind is a less important geologic agent than water, it does exert an appreciable influence on the topography of arid regions. Wind action is referred to as an eolian process, and all topographic features created by such a process are referred to as eolian landforms. Eolian landforms are typically depositional in nature; however, several types of erosional landforms exist as well.

a. **Erosional Features Created by Wind Action**. There are two processes by which wind accomplishes its erosional work-deflation and abrasion. Deflation is the lifting or rolling and subsequent removal of loose, dry sediments by wind action. The amount and size of material that is transported depends on the velocity of the wind (as the velocity increases, the wind carries increasingly larger particles). In general, only particles that range from fine silt or clay to coarse sand are capable of being transported by winds. As the wind-driven sand and silt impacts on exposed rock surfaces, a form of natural sandblasting, called abrasion, occurs. Both deflation and abrasion result in the formation of distinctive surficial features.

(1) **Desert Pavement**. When heterogeneous surficial mixtures of gravel, sand, and silt undergo erosion by deflation, the finer particle are removed, leaving behind only the particles that are too large to be transported. Eventually, a continuous remnant layer of gravel is left to protect the underlying heterogeneous material from further erosion. The gravel layer is referred to as a desert pavement due to its resemblance to cobblestone mosaics.

(2) **Ventifacts**. In windswept areas where abrasion is a predominant form of eolian erosion, sandblasting may result in the formation of smoothly polished face on exposed rock surfaces. If the wind direction or the position of the rock changes, additional facets may develop. A multifaceted rock shaped by wind abrasion is called a ventifact.

(3) **Other Erosional Eolian Features**. Several types of exotic erosional features may result from wind abrasion. For example, isolated rock masses have been carved into mushroom-shaped pedestals and bridgelike arches. In addition, holes, called windows, have been cut completely through rock walls.

b. **Depositional Features Created by Wind Action**. The wind velocity, with all transporting agents, eventually decrease at some point, and this decrease in wind velocity is accompanied by the deposition of suspended sediments. Initial deposition consists of relatively large particles at short distances from the source area. This is followed by later deposition of smaller particles farther from the place of origin. Sand-sized particles are commonly deposited in low hills or drifts called dunes, whereas finer sediments are generally deposited as smooth sheets.

(1) **Dunes**. As winds carrying a load of sediment encounter an obstruction, such as a boulder or bush, the wind velocity decreases and the sediment is subsequently deposited in the form of a hill or an elongate ridge of sand on the lee side of the barrier. This mound of sand is called a dune. Depending on the effectiveness of the wind, the abundance of vegetation, and the amount of sand available, the dune may take on one of many different shapes (see figure 2-14, page 2-22).

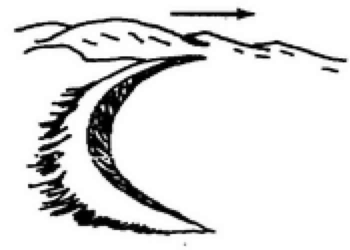
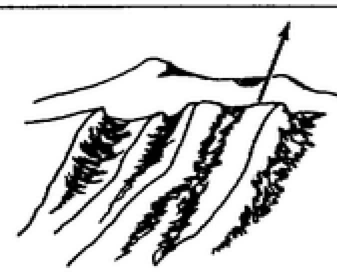
Dune Type	Definition and Occurrence	Illustration (Arrows Indicate Wind Directions)
Barchan	Crescent-shaped dunes with horns that point downwind. Dunes exhibit a gently inclined windward and a steeply inclined leeward slope. Isolated dunes migrate along hard, flat desert floors with constant wind speeds and limited sand supplies.	
Transverse	Dunes with long, wavelike ridges that are perpendicular to the effective wind direction. Common in areas of large sand supply, weak winds, and little vegetation. Often found along coast-lines but may grade inland to barchan dunes.	
Parabolic	Hairpin-shaped dunes that open upwind. Formed from the accumulation of sand along the leeward and lateral margins of a deflation basin. Occurs in areas with intermediate sand supplies and wind speeds and moderate vegetation.	
Longitudinal	Dunes with long, straight ridges that are parallel to the predominant wind direction. Found in barren areas where winds are persistent and the sand sup-ply is irregular. Dune ridges are sepa-rated by desert pavement.	

Figure 2-14. Dune types based on morphology

(2) **Loess**. The smooth sheets that result from the windblown deposition of relatively fine-grained sedimentary particles are called loess deposits. These homogeneous, nonstratified deposits, which have been derived from deserts, glaciated areas, or the floodplains of large rivers, are composed primarily of silt; however, they may also contain minor amounts of clay and/or very fine sand. The component particles are generally angular in shape, imparting a certain amount of stability to the overall loess deposit. Consequently, cliffs formed as a result of such things as stream erosion or road excavation are almost always vertical. Loess deposits occur over vast areas of the world, including the United States (the Mississippi

Valley, the Columbia Plateau, and the Central Great Plains), China, and Europe. In areas where loess is abundant, it is sometimes used as a building material for dwellings.

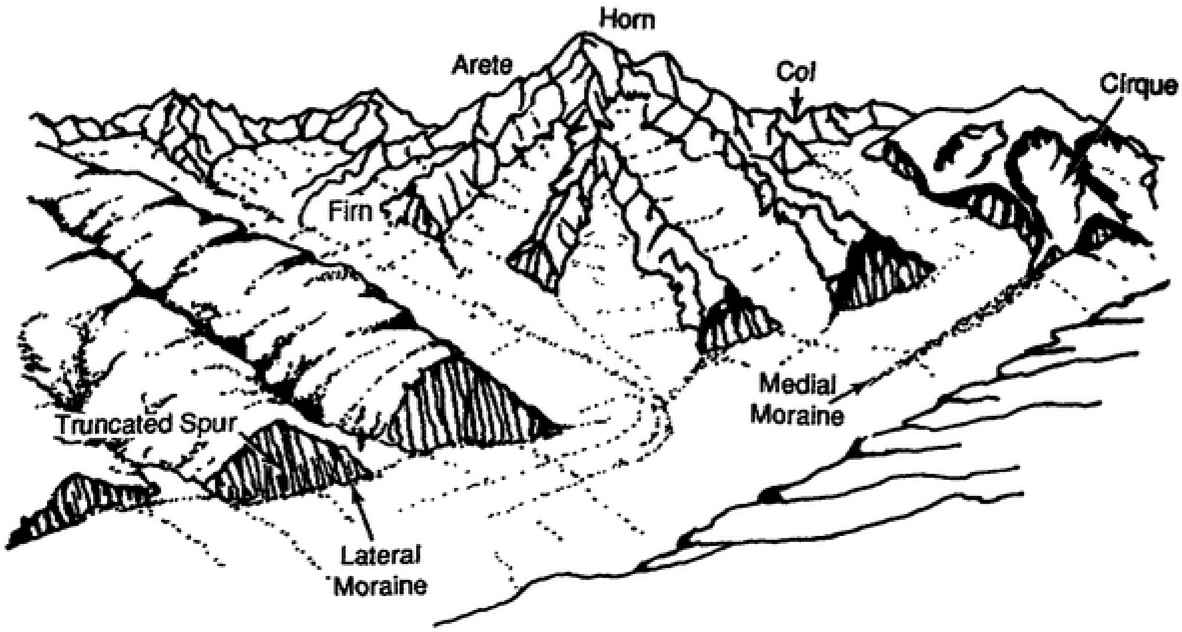
3. **Ice**. The recrystallization of perennial snow under overlying pressure results in the formation of ice. As more and more ice layers accumulate, the thickness of the entire mass eventually becomes sufficient to allow for the plastic behavior of the ice layers near the base of the mass. Under gravitational influence, these plastic layers may begin to flow, causing the entire ice mass to move downslope. This mobile accumulation of ice is called a glacier. Because glaciers are yet another transportation agent, their action results in the formation of both erosional and depositional features. As glaciers travel across an area, they tend to pluck rock fragments from the underlying bedrock and incorporate them into the ice mass. Once the fragments have been incorporated, they may serve as abrasion agents through the gouging, scraping, or scouring of any subsequent bedrock with which they come into contact. Both plucking and abrasion are erosional processes associated with glaciation. Depositional processes occur when the glacier begins to melt and can no longer carry its load. There are two basic categories of glaciation-alpine, or valley, glaciation and continental glaciation.

a. **Alpine or Valley Glaciers**. Large ice masses often accumulate in bowl-shaped hollows called cirques, which are located near the peaks of mountainous regions in areas of heavy precipitation and low temperatures. As the ice in the cirque becomes plastic, it begins to flow down the mountainside, forming long, narrow rivers that comprise alpine, or valley, glaciers. This type of glaciation is usually associated with erosional features, although the formation of depositional features is also possible.

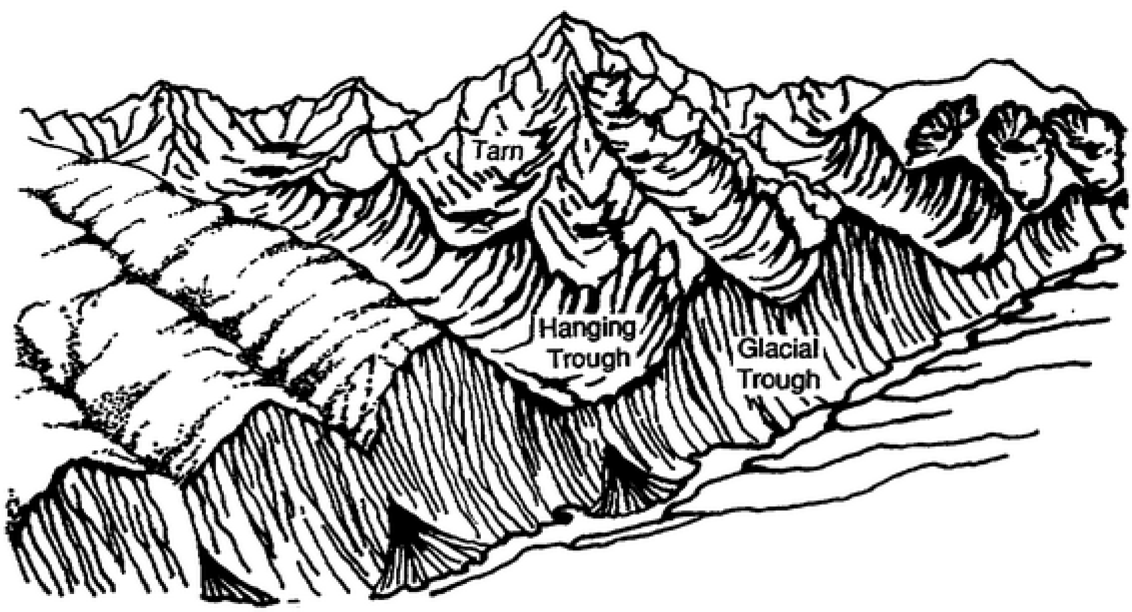
(1) **Erosional Features Created by Alpine Glaciation**. In addition to the plucked and abraded cirques previously mentioned, there are several other distinctive erosional features associated with alpine glaciation. Figure 2-15, page 2-24, depicts some of the more important erosional features associated with alpine glaciation.

An arete is a rough, irregular ridge that serves as a single wall separating two adjacent cirques. In areas where the headward erosion of these cirques has been extensive, a notch or pass, called a col, may be carved into the arete. A horn is a sharp, isolated peak formed by the intersection of the walls of three or more cirques. As glaciers flow down a mountainside, they continually deepen and widen their channels, eventually forming steep-sided, U-shaped glacial troughs. As the ice flows through these troughs, it cuts through numerous subordinate ridges that extend from the crest of the mountain. In this way, faceted structures known as truncated spurs are formed. Tributaries, like the main glacier, are also characterized by U-shaped valleys. However, the floors of these valleys are topographically higher than those of the main trough, so they are referred to as hanging troughs. The floors of erosional features, such as cirques and troughs, are highly irregular and uneven. This allows for the sporadic pooling of water, which results in the formation of small lakes called tarns.

(2) **Depositional Features Created by Alpine Glaciation**. Masses of sediment contained within a glacier tend to become streamlined as a result of ice flow; therefore, when the glacier melts, the unconsolidated particles are frequently deposited as elongate ridges known as moraines. These ridges commonly exist where sediments have been dragged along between the glacier and the valley wall (lateral moraine) or along the margin between two adjacent glaciers (medial moraine)(see figure 2-15, page 2-24). In addition, curvilinear deposits of unconsolidated material may accumulate at the terminus of a glacier. These



Relationship of landforms to ice placement.



Landforms exposed after removal of ice.

Figure 2-15. Area of alpine glaciation

sediments are referred to as terminal moraines. During warm periods, meltwaters associated with glaciers transport and deposit a wide variety of material (see figure 2-16).

Eskers are narrow, sinuous ridges of coarse-grained (sand- and gravel-sized) particles that mark the former pathways of meltwater streams flowing trough ice tunnels. Small, conical deposits of unconsolidated sediments that once rested atop the ice sheet and alluvial fan deposits that were originally built up against its edge are both referred to as kames. A kame terrace is a sand and gravel terrace formed between a melting glacier and its valley wall. Kame terraces are similar to lateral moraine except that they, like all other glaciofuvial deposits, are sorted and stratified. Lateral moraines, on the other hand, are composed of unsorted, unstratified debris. Figures 2-17, page 2-26, and 2-18, page 2-27, show several types of erosional and depositional landforms.

b. **Continental Glacier.** Continental glaciers, unlike alpine glaciers, are not confined to mountain valleys; rather, they occur as broad, relatively flat sheets of ice that cover large areas in arctic and polar regions. For example, the land masses of both Greenland and Antarctica are almost completely covered by huge continental glaciers. The major landforms associated with continental glaciers are depositional in nature, although a few minor erosional ones also exist.

(1) **Erosional Features of Continentally Glaciated Regions**. Continental glaciers, like alpine glaciers, are capable of grinding and scraping the underlying bedrock as the ice masses flow across an area. This results in the formation of rounded rock outcrops containing numerous grooves and striations that trend in the direction of ice movement. Continental

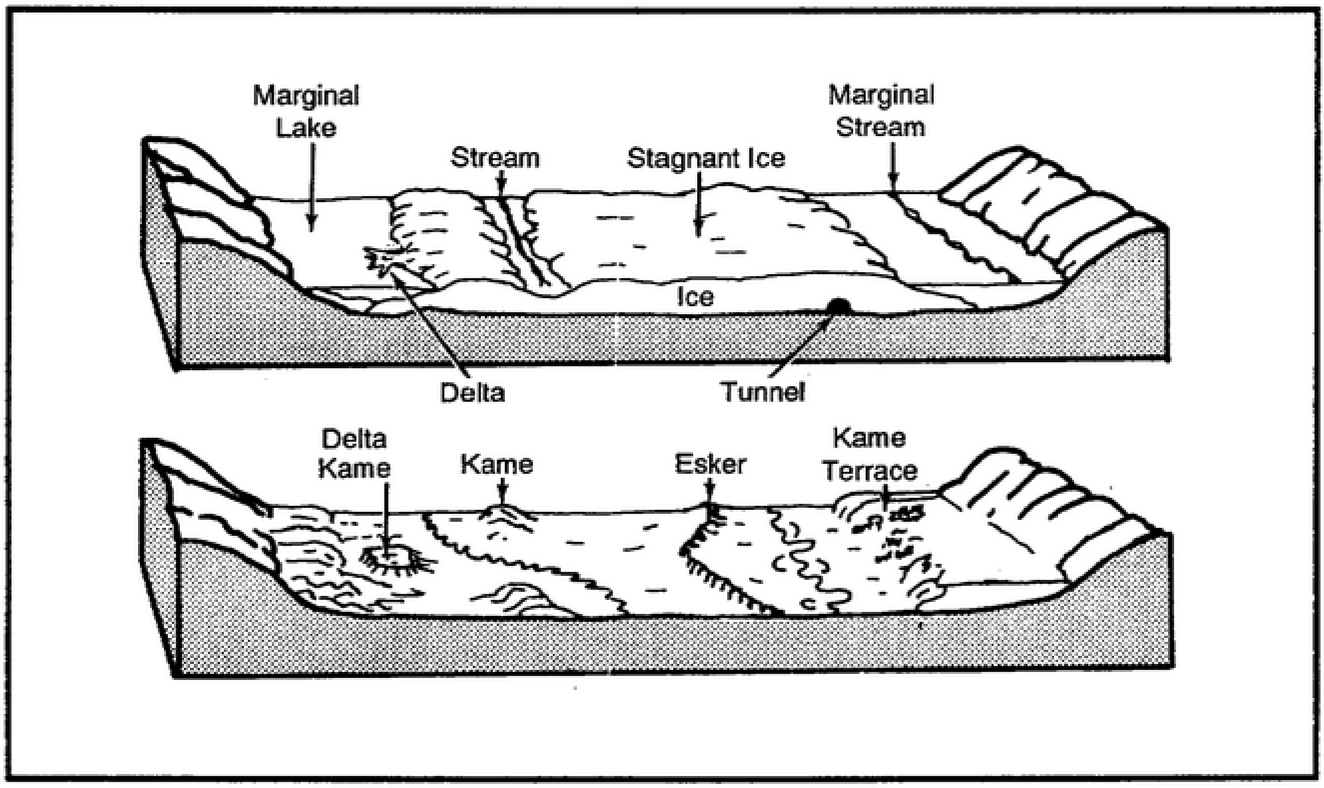
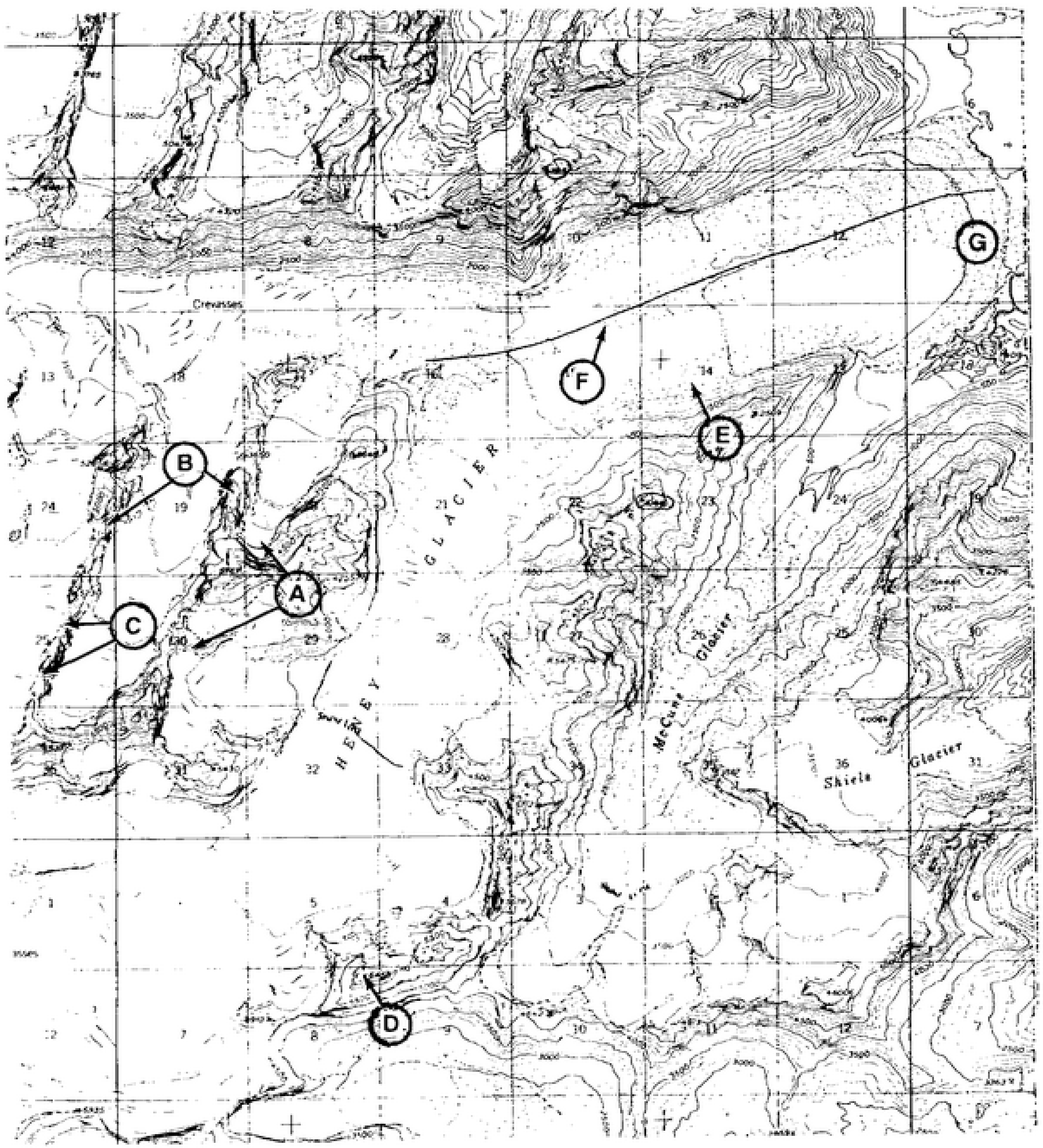


Figure 2-16. Glaciofluvial deposits associated with alpine glaciers



Note: Contour interval: 100 feet
A: Cirques
B: Aretes
C: Cols
D: Horns
E: Lateral moraine
F: Medial moraine
G: Terminal moraine

Figure 2-17. Topographic map of Cordova, Alaska

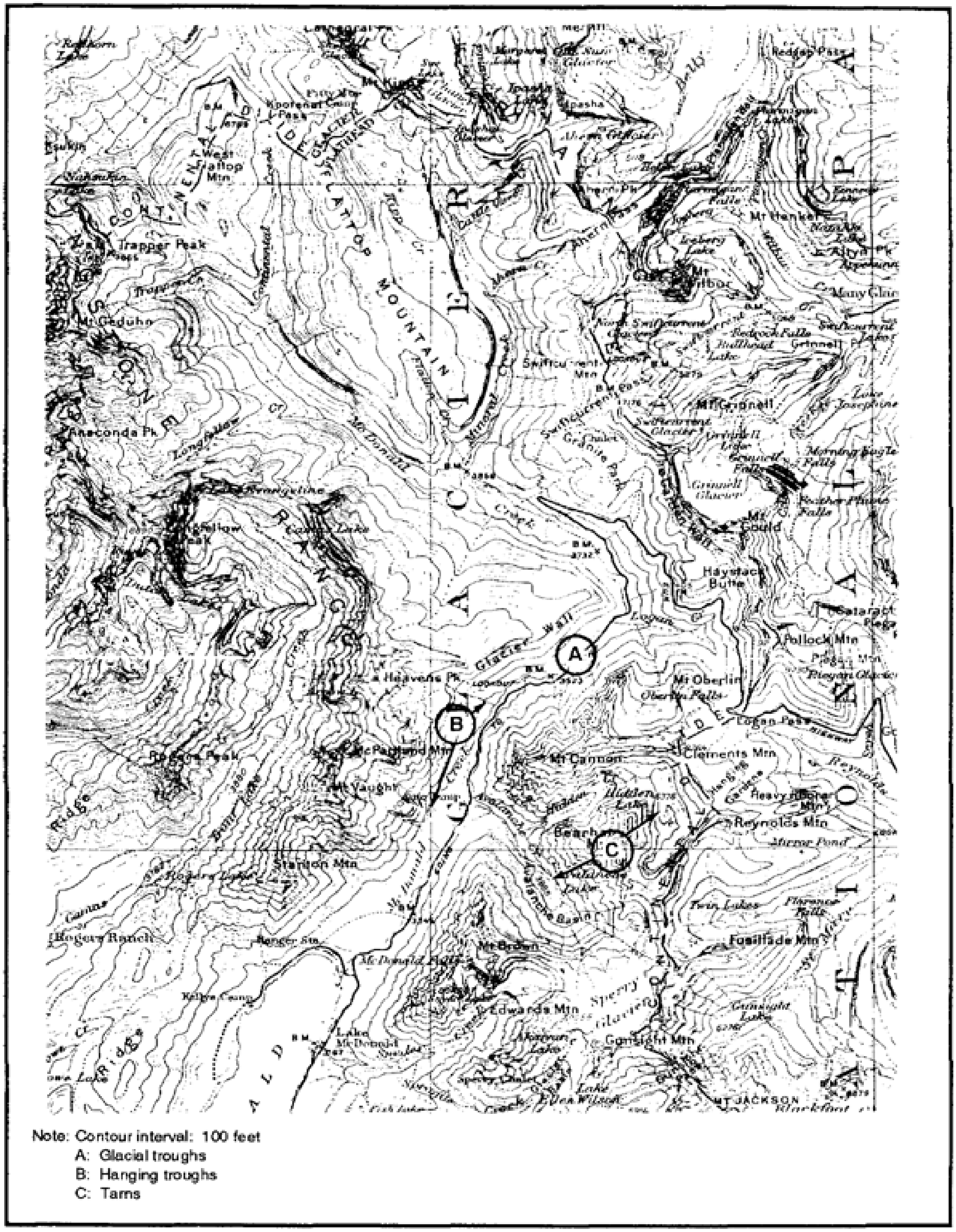


Figure 2-18. Topographic map of Chief Mountain, Montana

glaciers moving across a region underlain by incompetent bedrock or unconsolidated materials tend to churn and pluck these materials, incorporating clay- to boulder-sized particles into the glacier itself. Excavation of the substrate results in the formation of depressions that may later be filled with water, creating ponds and lakes.

(2) **Depositional Features of Continentally Glaciated Regions**. As the temperature rises, the ice begins to melt and the material contained within a glacier is either deposited in place as an unstratified glacial till or carried away by meltwaters and deposited in another location as a sorted, stratified glacial outwash. Figure 2-19 depicts the major depositional features associated with continental glaciers.

Meltwaters flowing on the surface of a glacier during periods of increased temperature eventually percolate downward through cracks in the ice to form streams. These streams, in turn, carve tunnels into the ice near the base of the glacier. Water emerging from the tunnel at the terminal edge of a glacier is generally choked with coarse-grained sediment; consequently, braided streams are common. In addition, during flood stages, fine-grained overbank deposits may be laid down, forming a broad, flat outwash plain. If the flow of water from a glacial tunnel is restricted by topography, a marginal lake may form. Often, deltas are deposited where glacial streams enter a marginal lake. As melting continues, large chunks of ice may break away from the main glacier, forming ice blocks when the detached ice occurs on land and icebergs when it occurs in marginal lakes. With further glacial melting, the ice sheet begins to retreat and additional depositional features become visible. Ground moraine is glacial till that has been spread evenly across the ground surface where the ice once flowed. Drumlins, which periodically interrupt the ground moraine, are asymmetrical, streamlined hills of gravel till deposited at the base of a glacier and oriented in a direction parallel to ice flow. Interlobate moraine is similar to the medial moraine discussed in Lesson 2.B.3.a.(2), page 2-23. Likewise, terminal moraine deposited by continental glaciation is similar to that deposited by alpine glaciation (see Lesson 2.B.3.a.(2), page 2-23). When there is a pause in the rate of glacial retreat, the terminal edge of an ice mass remained stationary for a period of time, allowing for the accumulation of recessional moraine. It is similar to terminal moraine except that it is fairly discontinuous and usually contains less sediment. Eskers, as previously mentioned, are long sinuous ridges of sand and gravel that mark the former pathways of ice tunnels. Once a glacier completely retreats from an area, a water source is no longer available to supply a marginal lake; consequently, evaporation may expose a lake bottom that is composed of fine-grained silts and clays. The delta that formed along the edge of the marginal lake may also be left high and dry, resulting in the formation of an elevated region called a delta kame. Finally, ice blocks that have been either partially or completely buried in the drift of the outwash plain may melt, forming depressions known as kettles. Figure 2-20 shows several depositional features associated with continental glaciation.

4. **Gravity and Mass Wasting**. Objects on the earth's surface tend to be attracted toward the center of the earth by a natural force called gravity. Gravity is the primary force responsible for mass wasting, which consists of the downslope movement and subsequent deposition of unstable material. Other factors that may contribute to the mass movement of earth materials include steep slopes, the lack of vegetation, the addition of water, the increased weight near the upper portion of a slope, the removal of material from the toe of a slope, and seismic activity. In addition, the type of material composing a slope greatly influences that slope's tendency toward failure. For example, cohesive sediments are generally stable and

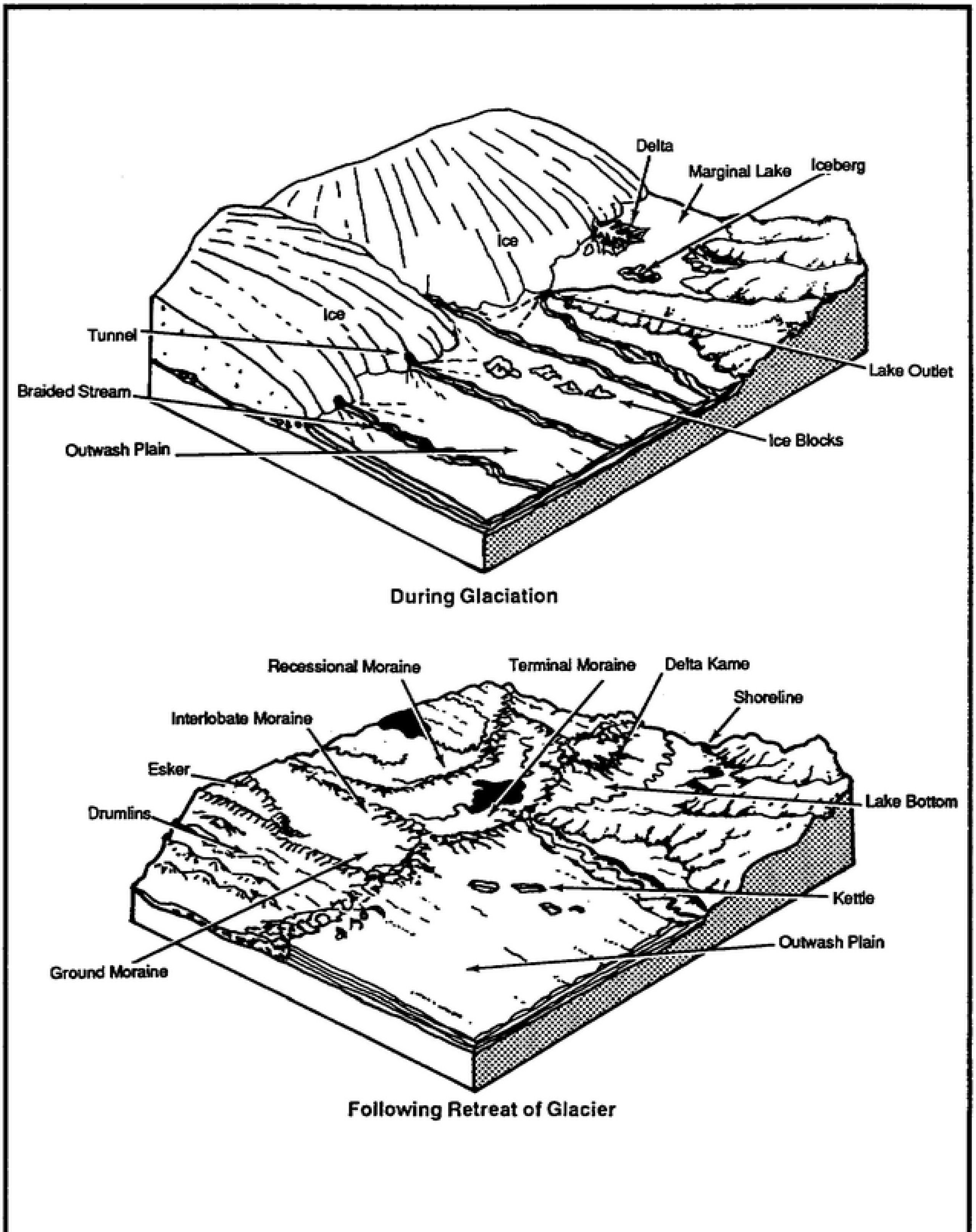


Figure 2-19. Depositional features associated with continental glaciation

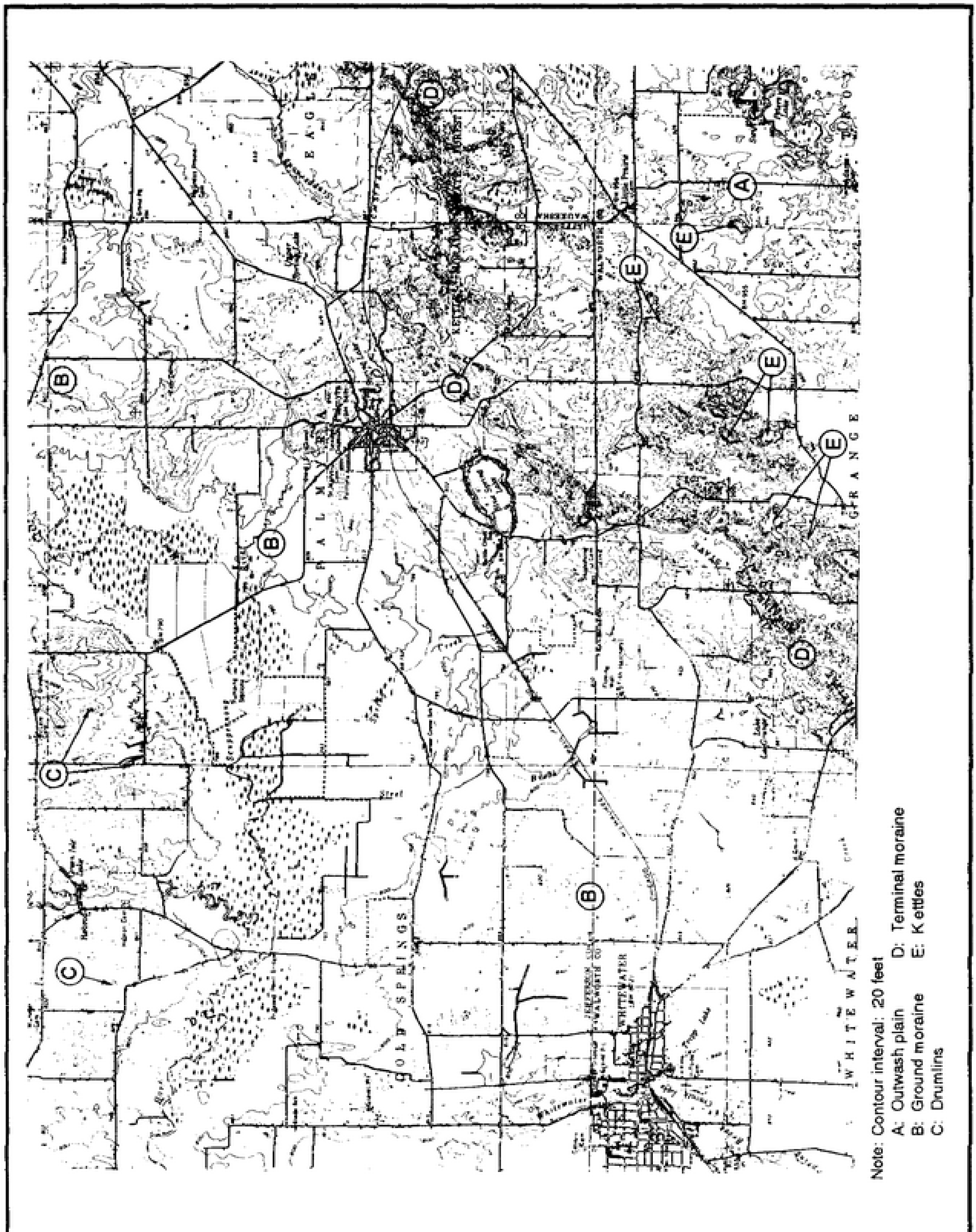


Figure 2-20. Topographic map of Whitewater, Wisconsin

tend to stand in vertical cliffs, whereas noncohesive materials are stable only at angles of about 30 to 40 degrees above the horizontal.

a. **Erosion by Mass Wasting**. The erosion associated with mass wasting may occur either slowly or rapidly. In any case, the most significant sign that an area has undergone erosion by mass wasting is the presence of a prominent scar that trends downslope and contains no vegetation.

(1) **Slow Erosion of Slopes**. Downslope movement that is imperceptible to the eye is considered to be slow. Therefore, in order to detect slow mass movements, it is necessary to utilize indirect methods, such as the recording of displaced fences or tilted telephone poles. There are several different types of slow downslope movement.

(a) **Creep**. This is the most widespread form of slow mass wasting. It is the imperceptible downhill movement of soil and unconsolidated rock material. Numerous processes, such as alternate heating and cooling, the growth of ice crystals, alternate wetting and drying, the actions of organisms, and the vibrations caused by seismic activity, result in minor disturbances of unconsolidated silt to boulder-sized particles. The disturbed particles are, in turn, acted upon by the force of gravity; consequently, they are transported minute distances downslope. Several episodes of disturbance (each of which is followed by downslope movement) may occur, resulting in transportation distances of a few millimeters to a few centimeters over a year's time.

(b) **Solifluction**. This is the slow downslope movement of consolidated material that has been saturated with water. This phenomenon most often occurs in arctic or subarctic regions during the summer months when the upper portions of the frozen ground begin to thaw, becoming saturated with water. The thawed portion may then move downslope in the form of a lobate mass, travelling at a rate of a few millimeters to several centimeters per year. As winter approaches, the mass refreezes, only to thaw once again with the return of summer.

(c) **Rock Glaciers**. Rainwater that inundates a loose accumulation of rock material may surround the individual component grains of the mass, filling any void spaces that are present. If the material has accumulated at high altitudes, the water within the mass may freeze, forming a rock glacier, which is a lobate mixture of rock and ice that, under pressure, flows downslope at a rate of up to one meter per year.

(2) **Rapid Erosion of Slopes**. In contrast to slow downslope movement, rapid erosion of slopes takes place at a perceptible rate. In fact, rapid types of mass movement may occur at rates of more than 30 meters per second. There are several types of mass wasting, and the classification of a particular event depends on the characteristics of the movement and the type of material involved.

(a) **Debris Flow**. This is a viscous downslope movement of undifferentiated material including soil, rock, vegetation, and man-made objects. Debris flows that are volumetrically composed of greater than 50 percent fine particles and also contain abundant water are termed mudflows. These types of flows, which are capable of transporting buildings as well as large boulders, are common where slopes are moderate, precipitation is intermittent, vegetation is sparse, and the clay or silt content is considerable.

(b) **Avalanche**. This is a mass of material ranging in composition from completely ice and snow to predominantly rock debris. Avalanches are capable of moving downslope at speeds in excess of 300 kilometers per hour; thus, they are the most rapid and usually the most destructive form of mass wasting.

(c) **Debris Slide**. A cliff of unconsolidated debris that is undercut by erosion tends to collapse along discrete shear planes, forming a debris slide. This type of mass wasting is common along major rivers during high-water stages.

(d) **Rockslide**. This is a rapid downslope movement of masses of bedrock that become detached along bedding planes, joints, or faults. Rockslides most commonly occur where sedimentary rocks dip steeply downslope. Because they often involve large masses of bedrock, rockslides may be very devastating.

(e) **Slump**. This is a form of rapid mass wasting in which a portion of unconsolidated, relatively homogeneous material slides downward, as a single unit, along a failure surface that is concave upward. A common cause of slumps is the removal of the toe of a slope by natural processes, such as stream erosion, or by human-induced factors, such as road excavation.

(f) **Rockfall**. Many steep cliffs are composed of fragmented bedrock that periodically becomes dislodged from the parent material. In these instances, individual rock masses ranging in size from sand grains to huge boulders may bounce down the side of the cliff, occasionally undergoing vertical free-fall. Consequently, there is very little interaction between the falling rock and the material remaining on the cliff face. This type of mass wasting is called a rockfall. Rockfalls are capable of transporting weathered bedrock up to two kilometers from its source area.

b. **Deposition by Mass Wasting**. Materials that have been transported downslope by mass wasting processes eventually reach a more or less stable position, usually at the base of a hill or cliff. Colluvium is a general term used to describe these incoherent materials, which normally occur as chaotic accumulations of angular particles. Types of colluvial deposits include talus and boulder field.

(1) **Talus**. Talus accumulations are fan-shaped deposits of broken rock fragments near the base of a cliff that have slowly accumulated as a result of numerous individual rockfalls. Talus deposits exhibit remarkably consistent slopes; they are generally inclined at angles of 34 to 35 degrees from the horizontal.

(2) **Boulder Fields**. Boulders carried to the base of a cliff by creep action may accumulate as large boulder fields.

LESSON 2

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. There is only one correct answer for each item. When you complete the exercise, check your answer with the answer key that follows. If you answer any item incorrectly, study again that part of the lesson that contains the portion involved.

1. Arches, pedestals, windows, and ventifacts are features created by which erosional agent?

2. True or False. Bird's-foot deltas are river-dominated deltas.

3. What is the feature depicted by the asterisk in the following topographic map?

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4. Name the two erosional processes associated with glaciation.

5. Which of the following is not a depositional feature?

   A. Delta
   B. Esker
   C. Stack
   D. Barchan dune

6. A type of mass wasting in which eroded material acting as a single unit slides downward along a concave-upward rupture surface is called ________________________.

7. What is a spit?

8. True or False. Alpine glaciation is normally associated with depositional features.

9. V-shaped gullies are characteristic of what type of underlying material?

10. True or False. The natural breakdown of rock material is called erosion.

LESSON 2

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

<u>**Item**</u>	<u>**Correct Answer end Feedback**</u>
1.	Wind (page 2-21, paragraphs (2), (3))
2.	True (page 2-16, paragraph 2)
3.	Alluvial fan (page 2-13, paragraph (a), and page 2-14, figure 2-7)
4.	Plucking and abrasion (page 2-23, paragraph 3)
5.	C. (stack) (page 2-20, paragraph (c))
6.	Slump (page 2-32, paragraph (e))
7.	A spit is an elongate ridge of sand and gravel that projects from the land into the sea. (page 2-20, paragraph (c))
8.	False (page 2-23, paragraph a)
9.	Noncohesive (for example, sand) (page 5-4, paragraph (a), and page 2-5, figure 2-1)
10.	False (page 2-1, Introduction paragraph)

If you experienced difficulty with any of the questions, review the appropriate sections before proceeding to Lesson 3.

LESSON 3

ANALYSIS OF UNCONSOLIDATED MATERIALS (SOILS)

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn to classify soils based on the Unified Soils Classification System (USCS) and to identity unknown soils using simple field procedures.

TERMINAL LEARNING OBJECTIVE

ACTION: Identify the composition, characteristics, and classification of soils and be able to identify the USCS types of various soil samples.

CONDITION: You will be given information on the classification and identification of soils.

STANDARD: Demonstrate the ability to interpret information and identify soils according to FMs 5-33, 5-545, and 5-410, and TM 5-330.

REFERENCES: The material contained in this lesson was derived from the following publications: FMs 5-33, 5-545, and 5-410, and TM 5-330.

INTRODUCTION

Unconsolidated materials, or soils, are the heterogeneous accumulation of disintegrated or decomposed rock and decayed organic matter. In some areas, these accumulations may be entirely absent, while in others they may be hundreds of feet thick. The characterization, classification, and identification of unconsolidated materials is important to military engineers for several reasons. An understanding of the composition, properties, and geographic distribution of various soil types is imperative in-

- Assessing the location, quality, and quantity of unconsolidated construction resources.
- Determining the feasibility of their use in the construction of roads and airfields.
- Rating the suitability of a site for construction of buildings and underground installations.
- Estimating the ease of excavation of shallow defensive positions as well as obstacles and barriers.
- Locating groundwater supplies.
- Predicting trafficability through specific areas.

Any available soil information concerning the area of interest should be gathered before the beginning of a military engineering project. During operations, the actual soil conditions encountered should be noted in order to update, verify, or modify the existing data bases and also to update intelligence estimates in cases where the new information has an impact on current or future operations.

PART A - SOURCES OF INFORMATION

There are several sources from which soil information may be obtained, including field investigations, maps, aerial photography, and soil reports. Written materials and maps may be acquired through various agencies, such as the United States Geological Survey, the Defense Mapping Agency, the United States Soil Conservation Service, the National Forest Service, and state geological agencies and private organizations. In addition, it is sometimes necessary to use materials prepared by foreign governments or companies. The classification schemes and accuracy of data vary from one source to another; therefore, many different sources should be used to achieve maximum accuracy and completeness of the data base. If the information sources are questionable, the uncertain reliability of the data should be noted. The collection of soil information is an ongoing process whereby the data base is continually updated with more current and increasingly accurate data. Once a sufficient amount of data has initially been collected, the analysis process begins with a critical review of the database materials on hand.

1. **Field Investigations**. The most accurate and reliable source of soil information, and consequently the most desirable, is actual field investigation. Unfortunately, the amount of reconnaissance that can realistically be completed is often insufficient to provide all the information needed. In fact, it is sometimes impossible to perform reconnaissance at all, especially in areas that are remote or in enemy possession. Therefore, other sources of information must be consulted.

2. **Maps**. There are several different types of maps that can supply information concerning the unconsolidated materials of an area, including soils, landform distribution, and geologic and topographic maps.

a. **Soil Maps**. Soil maps depict the geographic distribution of various types of unconsolidated surficial materials. Where available, these types of maps generally provide excellent sources of information. However, it should be noted that the majority of widely available soil maps are published by the United States Soil Conservation Service, an agency primarily concerned with the agricultural characteristics and applications of soils. Therefore, it may be necessary to interpret engineering classifications from such maps.

b. **Landform Distribution Maps**. Landform distribution maps depict the geographic distribution of various landforms that, in turn, may indicate certain soil characteristics. For example, a region depicted as rugged, mountainous terrain on a landform distribution map would likely contain stony, shallow soils, whereas soils measuring several meters in thickness may be found in areas depicted as floodplains or stream terraces. Landform distribution maps may even be used to estimate specific soil types and associated engineering properties. For example, areas depicted as swamps or marshes usually contain highly organic soils that have

low bearing strengths and little value as construction material. Although landform distribution maps are generally very good sources of information, they are normally produced for a limited function and area; therefore, they may be difficult to locate, obtain, and reproduce.

c. **Geologic Maps**. In the absence of more reliable data, geologic maps can be used to indicate possible overlying soil types and their geographic distributions. This is done by examining the geologic map to determine the rock types present and subsequently estimating the most likely weathering products derived from those rock types (see Lesson 2).

d. **Topographic Maps**. Topographic maps may supplement soil maps, landform distribution maps, or geologic maps by providing indirect data concerning the soils of an area. This indirect data may be obtained by analyzing the landforms and/or drainage patterns present on the map to determine the soil types most likely to be present. The relationship between drainage pattern and geologic materials is described in Lesson 2.B.1.a.(1)(b), page 2.4.

3. **<u>Aerial Photography</u>**. Analysis of aerial photographs is another good way to obtain soil information. For best results, the photographs should be of high quality and reasonably large scale (1:20,000 or larger). Interpretation is carried out by studying soil patterns resulting from the nature of the parent rock, the mode of deposition of the sediments, and the physical, climatic, and biological environments. One limitation of aerial photography is that, although soils are three-dimensional, the aerial photograph reveals only the two-dimensional soil surface; therefore, interpretation is somewhat restricted.

4. **<u>Soil Reports</u>**. Various types of soil reports may also be available. For example, the United States Soil Conservation Service has published reports concerning the soils of numerous counties in the United States. These reports are primarily tailored for agricultural users; however, the more recently published ones also contain information concerning the engineering properties of soils. Many foreign countries have also published soil reports that may be useful in analyzing a particular area of interest.

PART B - CLASSIFICATION OF SOILS

Although numerous soil classification schemes exist, engineers commonly use only those systems that base classification on the grain size and consistency of the component materials. In this way, several general soil categories may be identified.

1. **<u>General Soil Categories</u>**. Soils may be considered to belong to one of five broad categories based on the grain size, consistency, and chemical characteristics of the component particles.

a. **Gravel**. Gravels are coarse materials ranging from 4.7 millimeters to 76 millimeters in diameter.

b. **Sand**. Sand grains are also coarse, ranging in diameter from 0.07 millimeter to 4.7 millimeters.

c. **Silt**. Silt is a relatively fine-grained material that lacks plasticity and is composed of individual particles ranging from 0.004 millimeter to 0.07 millimeter in diameter.

d. **Clay**. Clay is a cohesive, highly plastic material made up of microscopic particles less than 0.004 millimeter in diameter.

e. **Organic Mater**. Organic matter consists of relatively fine-grained, partially decomposed animal or vegetable material.

In order to more clearly define the specific parameters for each of these individual soil types, it is necessary to separately discuss the classification of soils based on the grain size as well as the consistency of the component materials.

2. **Classification of Soils Based on Grain Size**. Soils may be classified as gravels, sands, silts, or clays based solely on the size of the individual component grains. As previously mentioned, gravels range in size from 4.7 millimeters to 76 millimeters in diameter, sands range from 0.07 millimeter to 4.7 millimeters in diameter, silts range from 0.004 millimeter to 0.07 millimeter in diameter, and clays are comprised of particles with diameters less than 0.004 millimeter.

In reality, soils are seldom made up of a single component; that is, pure gravel, sand, silt, or clay is rarely encountered. More commonly, soils consist of particles of various sizes mixed in varying proportions. The component grain sizes and their respective proportions may be determined by Materials Quality Specialists (Military Occupational Specialty (MOS) 51G) through the use of sieve analyses and/or settling tube analyses.

a. **Sieve Analysis**. A sieve analysis begins by recording the weight of an oven-dried soil sample on DD Form 1206 (see figure 3-1). Next, an attempt is made to pass the soil through a series of standard-sized sieves containing progressively smaller openings (see figure 3-2, page 3-6). Particles with diameters larger than the openings of a particular sieve are not allowed to pass through the sieve and are said to be "retained" at that point. The weight of material retained on each of the sieves is recorded on DD Form 1206 (see figure 3-1). The weight of the material passing each of the sieves may then be determined by subtracting the weight of material that has been retained on each of the preceding sieves from the weight of the original sample. These weights are normally converted to percentages by dividing them by the weight of the original sample and multiplying the quotient by 100.

Common sieves used by military engineers in a sieve analysis include 2-inch, 1 1/2-inch, 1-inch, and 3/4-inch sieves that have 2-inch, 1 1/2-inch, 1-inch, and 3/4-inch openings respectively, as well as US Standard Number 4, 10, 20, 40, 100, and 200 sieves, which contain 4, 10, 20, 40, 100, and 200 openings per linear inch respectively. The US Standard Number 4 sieve serves to separate gravel-sized particles from those particles that are smaller than gravel, whereas the Number 200 sieve is used to separate coarse materials (gravel- and sand-sized particles) from fine materials (silt- and clay-sized particles). In some instances, fine materials (silts and clays) adhere to the coarse materials (gravels and sands) to the extent that they cannot be separated by dry sieving. In such cases, it is necessary to soak the sample in water and attempt to wash it through the Number 200 sieve. Both the material retained on the sieve and the material that has passed through the sieve must then be oven-dried and the sieve analysis

SIEVE ANALYSIS DATA

1. DATE STARTED: 22 FEB 91
2. PROJECT: BRAVO AIRFIELD
3. EXCAVATION: 1+00
4. DATE COMPLETED: 28 FEB 91
5. SAMPLE DESCRIPTION: LIGHT BROWN SANDY SOIL
6. SAMPLE NUMBER: 1A
7. PREWASHED (√ one): XX YES | NO
8. ORIGINAL SAMPLE WEIGHT: 2459
9. + #200 SAMPLE WEIGHT: 2359
10. −#200 SAMPLE WEIGHT: 100

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE + SAMPLE	14. WEIGHT RETAINED	15. CUMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
1½	202					
1	231					
½	210	210	0	0	0	100.0
¼	230	624	394	394	16.0	84.0
#4	205	332	127	521	5.2	78.8
#8	225	691	466	987	19.0	59.8
#20	215	612	397	1384	16.2	43.6
#60	235	581	346	1730	14.1	29.5
#100	250	612	362	2092	14.7	14.8
#200	260	515	255	2347	10.4	4.4

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum Column 14): 2347
19. ERROR (8 - 23): 2459-2457 = 2
20. WEIGHT SIEVED THROUGH #200 (Weight in pan): 270-260 = 10
21. WASHING LOSS (8 - (9 + 10)): 2459-(2359+100) = 0
22. TOTAL WEIGHT PASSING #200 (20 + 10): 10+100 = 110
23. TOTAL WEIGHT OF FRACTIONS (18 + 22): 2457

24. REMARKS

USCS SP
PERCENT-G 21.2
PERCENT-S 74.4
PERCENT-F 4.4

25. ERROR (Percent)

$\frac{\text{ERROR (19)}}{\text{ORIGINAL WT (8)}} \times 100 =$

$\frac{2}{2459} \times 100 = .08$

26. TECHNICIAN: Joe Blob PV2
27. COMPUTED BY (Signature): Joe Blob PV2
28. CHECKED BY (Signature): Fred Jones SSG

DD Form 1206, DEC 86 *Previous editions are obsolete.*

Figure 3-1. Sample sieve analysis data sheet

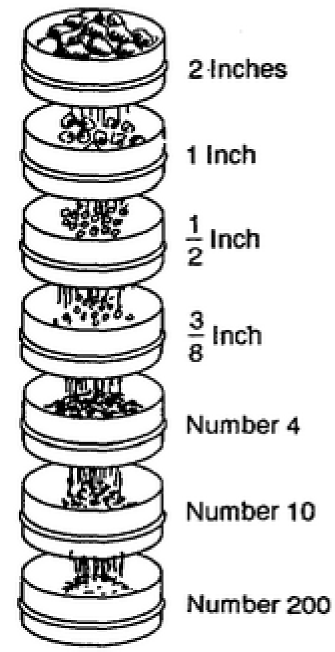


Figure 3-2. Dry sieve analysis

conducted as explained above. The results of a sieve analysis may be recorded graphically using DD Form 1207 (see figure 3-3).

The horizontal axis of this chart is used to plot the various sieve sizes used in the analysis, while the percentage of material passing each of those sieves is plotted on the vertical axis. Once points have been established on the graph using this procedure, they may be connected by a line, called the grain size distribution curve. This curve allows for the ready visualization of the distribution of particle sizes within a particular soil. It is important to note that gravel-sized particles are represented by the portion of the curve that lies to the left of the vertical line signifying the US Standard Number 4 sieve size; sand-sized particles are represented by the portion of the curve that lies between the vertical lines signifying the Number 4 and Number 200 sieve sizes; and fines (silts and clays) are represented by the portion of the curve that lies to the right of the vertical line signifying the Number 200 sieve size.

b. **Settling Tube (Wet Mechanical) Analysis**. The US Standard Number 200 sieve size is, for all practical purposes, the lower limit for use in sieve analysis. Because the Number 200 sieve size allows the passage of both silt- and clay-sized particles, an alternate method for the further classification of fine-grained materials is required. One such method is the settling tube (wet mechanical) analysis method, which operates on the principle that relatively large particles settle from suspension in water exponentially faster than smaller particles. Following this principle, water may be added to a fine-grained soil and the mixture agitated so that individual soil particles become suspended. The sedimentation rates of the particles may then be recorded and used to determine particle sizes.

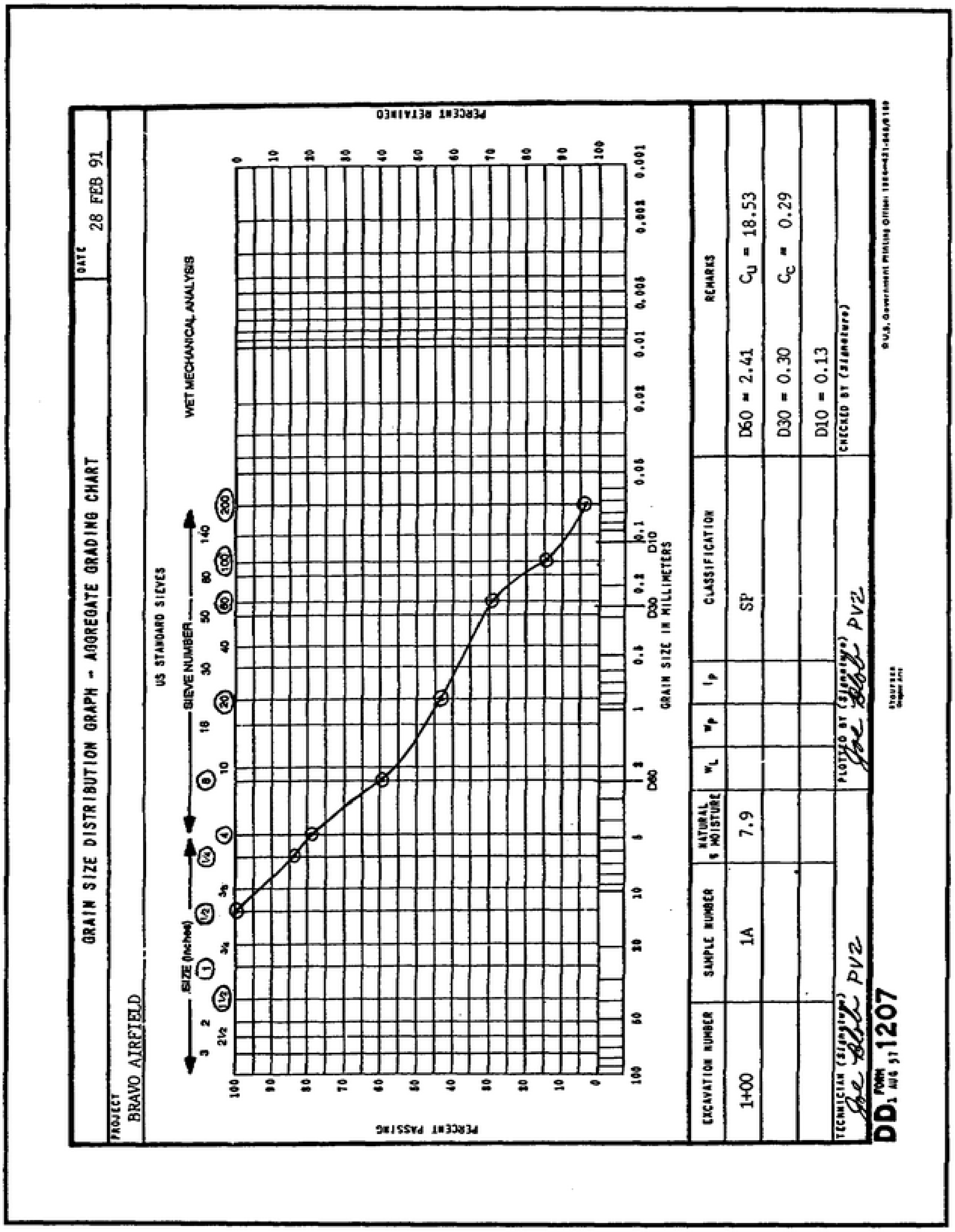


Figure 3-3. Sample grain-size distribution curve from sieve analysis

3. **<u>Classification of Soils Based on Consistency</u>**. Atterberg limit and a plasticity chart may be used to classify relatively fine-grained soils (those that pass a Number 40 sieve) on the basis of their consistencies.

a. **Atterberg Limits**. Atterberg limits describe the moisture content of a soil exhibiting certain physical properties. Three parameters define the Atterberg limits of a soil--the plastic limit (PL), the liquid limit (LL), and the plasticity index (PI).

(1) **Plastic Limit**. If water is slowly added to a dry, fine-grained soil, the soil will eventually be transformed from a semisolid state to a plastic state, as evidenced by its ability to be rolled into thin, 3-millimeter-diameter threads. The water content, expressed as a percentage by weight, of the soil at that point is called the PL.

(2) **Liquid Limit**. If additional water is added to a soil already in its plastic state, the soil will eventually behave as a liquid. The water content, expressed as a percentage by weight, of the soil at that point is called the LL.

(3) **Plasticity Index**. The difference in moisture content between the LL and the PL of a soil is known as the PI. That is:

$$PI = LL - PL$$

The PI represents the range of moisture content over which the soil will exhibit plastic behavior. For example, a soil with a high PI is one that will behave plastically over a wide range of moisture contents.

Complete procedures and details for conducting tests to determine the PL and LL of a soil are outlined in TM 5-530.

b. **Plasticity Chart**. The Casagrande Plasticity Chart (Engineer (ENG) Form 4334)(see figure 3-4) may be used to plot the LL (horizontal axis) and the PI (vertical axis) of a specific soil sample. Depending on the location of the plot, a fine-grained soil may be considered to be either a clay or a silt or an organic-type material.

4. **<u>Unified Soil Classification System</u>**. As mentioned earlier, soils commonly consist of particles of various sizes mixed in varying proportions. Each individual component, therefore, contributes its own unique characteristics to the mixture. In order to describe the engineering classifications of such heterogeneous mixtures, the US Army uses what is known as the USCS (see table 3-1, page 3-11). Under this system, soils are divided into two categories-coarse-grained and fine-grained.

a. **Coarse-Grained Soils**. If at least half of the material, by weight, of a soil is made up of particles that are larger than the openings in a Number 200 sieve, the soil is considered to be coarse-grained. (A particle the size of an opening in a Number 200 sieve is about the smallest particle size distinguishable to the unaided eye). Coarse-grained soils are further classified as gravels or sands.

(1) **Gravels**. A coarse-grained soil is classified as a gravel if at least half of the coarse fraction, by weight, consists of particles larger than the opening. In a Number 4 sieve (that is,

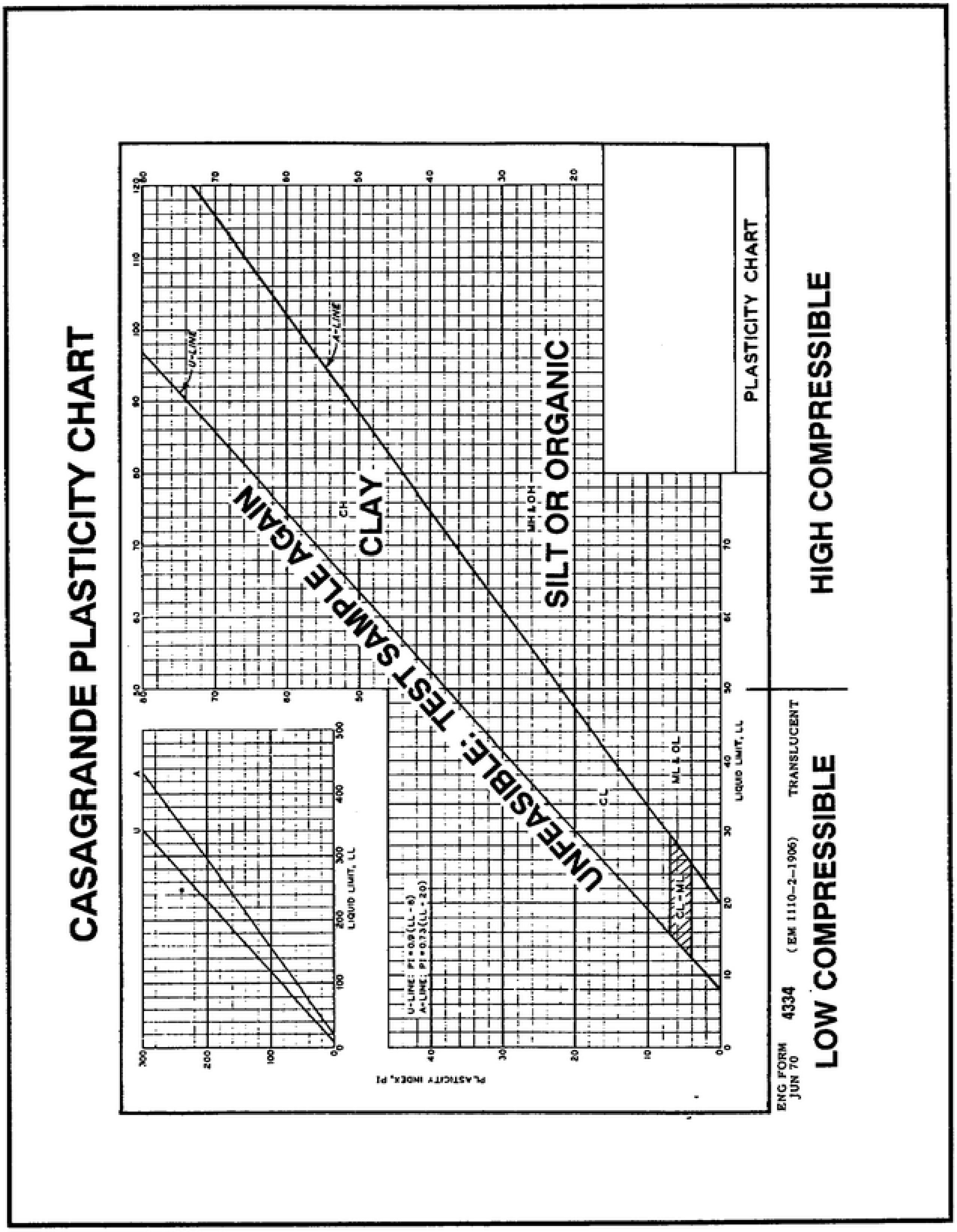


Figure 3-4. Sample Casagrande Plasticity Chart

they are larger than 1/4 inch in diameter). These types of soils are symbolized by using a two-letter designation, with "G" being the first letter, indicating that the soil is predominantly composed of gravel-sized particles. Gravels may be further classified based on the amounts of fines associated with the coarse particles.

(a) **Gravels Containing Little or No Fine Material**. Gravels made up of less than five percent, by weight, of fine particles (materials with diameters less than the size of the openings in a Number 200 sieve) may be classified as well-graded or poorly graded.

- Well-Graded Gravels. Gravels that contain a relatively uniform distribution of a wide range of particle sizes are referred to as well-graded gravels or gravel-sand mixtures. Figure 3-5, page 3-13, illustrates the possible particle size distribution within a well-graded soil. Well-graded soils are symbolized by attaching the letter "W" to the symbol for the predominant soil type; therefore, the symbol GW signifies a well-graded gravel.

- Poorly Graded Gravels. Gravels that do not contain a relatively uniform distribution of a wide range of particle sizes are said to be poorly graded gravels or gravel-sand mixtures. Figure 3-6, page 3-13 shows the particle -size distributions of two types of poorly graded soils. Poorly graded soils are symbolized by attaching the letter "P" to the symbol for the predominant soil type; therefore, the symbol GP signifies a poorly graded gravel.

(b) **Gravels Containing Appreciable Amounts of Fine Material**. Gravels made up of greater than 12 percent, by weight, of fine particles may be further classified based on the predominate type of fines present.

- Silty Gravels. A gravel containing greater than 12 percent, by weight, of fine material, with silt being the predominant type of fine present, is called a silty gravel or a gravel-sand-silt mixture. Because the letter "M" is used to represent silts, silty gravels are designated by the symbol GM.

- Clayey Gravels. A gravel containing greater than 12 percent, by weight, of fine material, with clay being the predominant type of fine present, is called a clayey gravel or a gravel-sand-clay mixture. Because the letter "C" is used to represent clays, clayey gravels are designated by the symbol GC.

(c) **Gravels Containing Moderate Amounts of Fine Material**. Gravels that contain between 5 and 12 percent, by weight, of fine material are considered to be borderline soil types and are assigned a dual symbol. For example, such a soil with a well-graded coarse fraction and a fine fraction predominantly composed of silt would be identified by the symbol GW-GM. Other possible soil types are GW-GC, GP-GM, and GP-GC.

(2) **Sands**. A coarse-grained soil is classified as a sand if more than half of the coarse fraction, by weight, consists of particles smaller than the openings in a Number 4 sieve (that is, they are smaller than 1/4 inch in diameter). These types of soils are symbolized by using a two-letter designation, with "S" being the first letter, indicating that the soil is predominantly composed of sand-sized particles. Sands may be further classified based on the amounts of fines associated with the coarse particles.

Table 3-1. Unified soil classification (including identification and description)

Major Divisions					Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights)		
1		2			3	4	5		
Coarse-grained soils More than half of the material is larger than No 200 sieve size	(The No 200 sieve size is about the smallest particle visible to the naked eye)	Gravels More than half of coarse fraction is larger than No 4 sieve size	(For visual classification, the 1/4 inch size may be used as equivalent to the No 4 sieve size)	Clean gravels (little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Wide range in grain sizes and substantial amounts of all intermediate particle sizes		
					GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing		
				Gravels with fines (appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below).		
					GC	Clayey gravels, gravel-sand-clay mixtures	Plastic fines (for identification procedures, see CL below).		
		Sands More than half of coarse fraction is smaller than No 4 sieve size		Clean sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes		
					SP	Poorly graded sands or gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing		
				Sands with fines (appreciable amount of fines)	SM	Silty sands, sand-silt mixture	Nonplastic fines or fines with low plasticity (for identification procedures, see ML below).		
					SC	Clayey sands, sand-clay mixtures	Plastic fines (for identification procedures see CL below)		
Fine-grained soils More than half of the material is smaller than No 200 seive size							Identification procedures on fraction smaller than No 40 sieve size		
							Dry strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near PL)
		Silts and clays LL < 50			ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to slow	None
					CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	None to very slow	Medium
					OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow	Slight
		Silts and clays LL > 50			MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Slight to medium	Slow to none	Slight to medium
					CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High
					OH	Organic clays of medium to high plasticity, organic silts	Medium to high	None to very slow	Slight to medium
		Highly organic soils			Pt	Peat and other highly organic soils	Readily idenified by color, odor, spongy feel, and frequently by fibrous texture		

(1) Boundary classifications: soils possessing characteristics of two groups are designated by combinations of group symbols. For example (GW - OC), well-graded gravel-sand mixutre with clay binder.

(2) All sieve sizes on this chart are US standard.

Table 3-1. Unified soil classification (including identification and description) (cont)

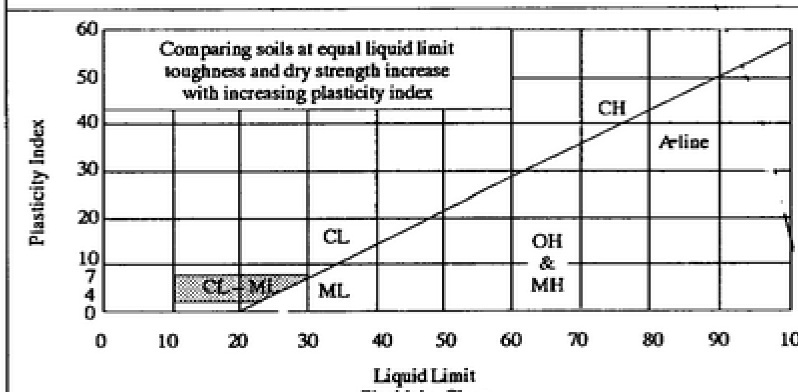
Information Required for Describing Soils	Laboratory Classification Criteria			
6	7			
For undisturbed soils, add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics. Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 inch maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; aluvial sand; (SM)	Use grain-size curve in identifying the fractions as given under field identification.	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No 200 sieve size) coarse-grained soils are classified as follows: Less than 5% = GW, GP, SW, SP More than 12% = GM, GC, SM, SC 5% to 12% = borderline cases requiring use of dual symbols	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			Not meeting all gradation requirements for (GW)	
			Atterberg limits below A-line or PI < 4	Above A-line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Atterberg limits above A-line with PI > 7	
			$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			Not meeting all gradation rquirements for SW	
			Atterberg limits below A-line or PI < 4	Above A-line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Atterberg limits above A-line with PI > 7	
For undisturbed soils, add information on structure, stratification, consistency in undisturbed and remolded states, and moisture and drainage conditions. Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)		 Plasticity Chart For laboratory classification of fine-grained soils		

Table 3-1. Unified soil classification (including identification and description) (cont)

Field Identification Procedures for Fine-Grained Soils or Fractions

These procedures are to be performed on the minus No 40 sieve size particles, approximately 1/64 inch for field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (reaction to shaking)

After removing particles larger than Number 40 sieve size, prepare a pat of moist soil with a volume of about ½ cubic inch. Add enough water, if necessary, to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat, which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction, whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than Number 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the charcter and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the (CH) group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty, whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the Number 40 sieve size are removed, a specimen of soil about ½ cubic inch in size is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about ⅛ inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation, the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity or materials such as kaolin-type clays and organic clays that occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

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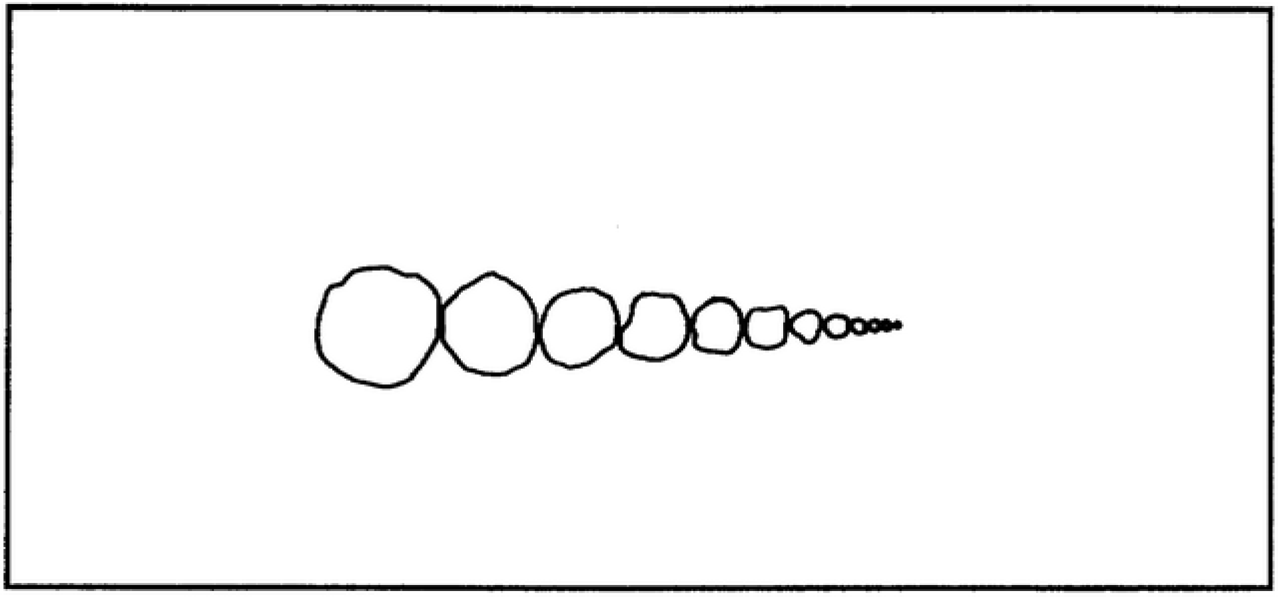

Figure 3-5. Particle size distribution of a well-graded soil

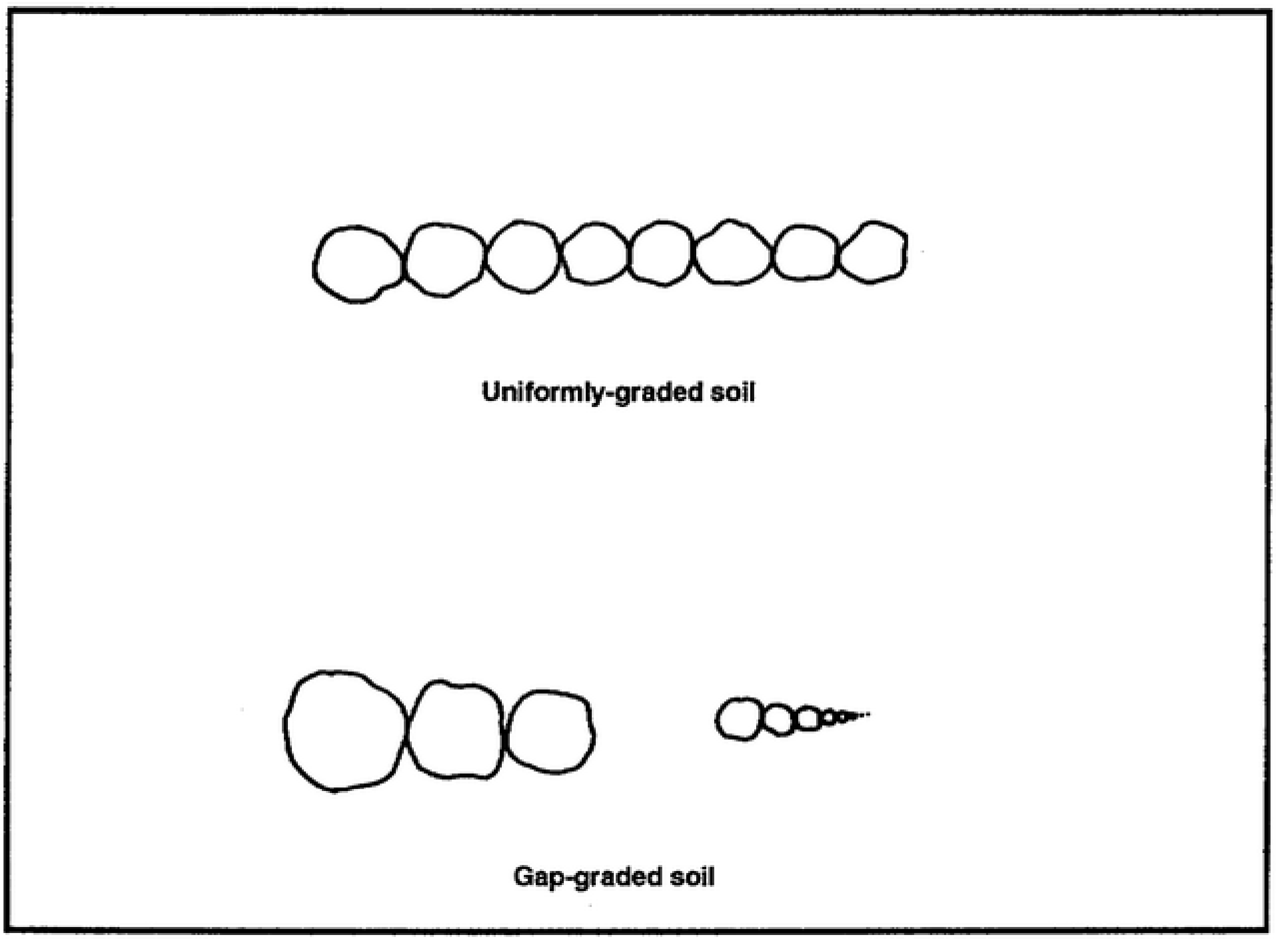

Figure 3-6. Particle size distributions of poorly graded soils

(a) **Sands Containing Little or No Fine Material**. Sands made up of less than five percent, by weight, of fine particles (materials with diameters less than the size of the openings in a Number 200 sieve) may be classified as well-graded or poorly graded.

- Well-Graded Sands. Sands that contain a relatively uniform distribution of a wide range of particle sizes are referred to as well-graded sands or gravelly sands. As previously mentioned, well-graded soils are symbolized by attaching the letter "W" to the symbol for the predominant soil type; therefore, the symbol SW signifies a well-graded sand.

- Poorly Graded Sands. Sands that do not contain a relatively uniform distribution of a wide range of particle sizes are said to be poorly graded. As stated previously, poorly graded soils are symbolized by attaching the letter "P" to the symbol for the predominant soil type; therefore, the symbol SP signifies a poorly graded sand or a gravelly sand.

(b) **Sands Containing Appreciable Amounts of Fine Material**. Sands made up of greater than 12 percent, by weight, of fine particles may be further classified based on the predominate type of fines present.

- Silty Sands. A sand containing greater than 12 percent, by weight, of fine material, with silt being the predominant type of fine present, is called a silty sand or a sand-silt mixture. Because the letter "M" is used to represent silts, silty sands are designated by the symbol SM.

- Clayey Sands. A sand containing greater than 12 percent, by weight, of fine material, with clay being the predominant type of fine present, is called a clayey sand or a sand-clay mixture. Because the letter "C" is used to represent clays, clayey sands are designated by the symbol SC.

(c) **Sands Containing Moderate Amounts of Fine Material**. Sands that contain between 5 percent and 12 percent, by weight, of fine material are considered to be borderline soil types and are assigned a dual symbol. For example, such a soil with a well-graded coarse fraction and a fine fraction predominantly composed of silt would be identified by the symbol SW-SM. Other possible soil types are SW-SC, SP-SM, and SP-SC.

b. **Fine-Grained Soils**. If more than half of the material, by weight, of a soil is made up of particles that are smaller than the openings in a Number 200 sieve, the soil is considered to be fine-grained. Fine-grained soils are further classified based on their positions as plotted on the ENG Form 4334 (see figure 3-4, page 3-9).

(1) **Liquid Limit Less Than 50**. Soils that have a LL less than 50 (those that plot to the left of the vertical line representing a LL of 50 on ENG Form 4334) are said to have low plasticity. These types of soils are symbolized by using a two-letter designation, with the second letter being an "L" indicating that the soils exhibit low plasticity. Soils with low plasticity may be further classified based on their plotted positions relative to the "A" line on ENG Form 4334.

(a) **Silts With Low Plasticity**. Fine-grained, inorganic soils that plot to the left of the vertical line representing a LL of 50 and below the "A" line on ENG Form 4334 are referred to as silts with low plasticity. As mentioned previously, the letter "M" indicates silt-sized

material and the letter "L" refers to low plasticity; therefore, the symbol ML is used to represent a silt with low plasticity.

(b) **Clays With Low Plasticity**. With the exception of one small area, fine-grained, inorganic soils that plot to the left of the vertical line representing a LL of 50 and above the "A" line on ENG Form 4334 are referred to as clays with low plasticity, or lean clays. As mentioned previously, the letter "C" indicates clay-sized material and the letter "L" refers to low plasticity; therefore, the symbol CL is used to represent a clay with low plasticity.

(c) **Low Plasticity Clay/Silt Mixtures**. Soils that plot above the "A" line on ENG Form 4334 and have LLs ranging from 10 to 30 and PIs ranging from 4 to 7 are called low plasticity clay/silt mixtures. These types of soils are represented by the symbol CL-ML, indicating that they are low plasticity soils comprised of a mixture of clay- and silt-sized particles.

(d) **Organics With Low Plasticity**. Fine-grained, organic soils that plot to the left of the vertical line representing a LL of 50 and below the "A" line on ENG Form 4334 are referred to as organics with low plasticity. The letter "O" is used to indicate organic material; therefore, the symbol OL refers to organic material with low plasticity.

(2) **Liquid Limit Greater Than 50**. Soils that have a LL greater than 50 (those that plot to the right of the vertical line representing a LL of 50 on ENG Form 4334) are said to have high plasticity. These types of soils are symbolized by using a two-letter designation, with the second letter being an "H," indicating that the soils exhibit high plasticity. Soils with high plasticity may be further classified based on their plotted positions relative to the "A" line on ENG Form 4334.

(a) **Silts With High Plasticity**. Fine-grained, inorganic soils that plot to the right of the vertical line representing a LL of 50 and below the "A" line on ENG Form 4334 are referred to as silts with high plasticity. Loess is a good example of this type of soil. As mentioned previously, the letter "M" indicates silt-sized material and the letter "H" refers to high plasticity; therefore, the symbol MH is used to represent a silt with high plasticity.

(b) **Clays With High Plasticity**. Fine-grained, inorganic soils that plot to the right of the vertical line representing a LL of 50 and above the "A" line on ENG Form 4334 are referred to as clays with high plasticity, or fat clays. The gumbo clays of the southern United States are good examples of this type of material. As mentioned previously, the letter "C" indicates clay-sized material and the letter "H" refers to high plasticity; therefore, the symbol CH is used to represent a clay with high plasticity.

(c) **Organics With High Plasticity**. Fine-grained, organic soils that plot to the right of the vertical line representing a LL of 50 and below the '"A" line on ENG Form 4334 are referred to as organics with high plasticity. As mentioned, the letter "O" is used to indicate organic material; therefore, the symbol OH refers to organic material with high plasticity.

(3) **Highly Organic Soils**. If the color, odor, or fibrous texture of a fine-grained soil indicates that it is composed largely of organic material, the soil is termed peat. These types of soils commonly contain particles of leaves, grass, branches, or other fibrous vegetable material. The symbol for peat is the two-letter designation, Pt.

5. **<u>Examples of Soil Classification</u>**. A few examples are provided here in order to illustrate the classification of soils based on the USCS.

a. **Example 1.**

Given:

(1) The percent of material retained on the Number 200 sieve: 60 percent
(2) The percent of coarse material retained on the Number 4 sieve: 30 percent
(3) The material passing the Number 200 sieve is mostly clay, as evidenced by a settling tube analysis or by plotting the relatively fine fraction on ENG Form 4334.

Soil Type: SC

b. **Example 2.**

Given:

(1) The percent of material retained on the Number 200 sieve: 20 percent
(2) The LL of material passing the Number 40 sieve: 70
(3) The PI of material passing the Number 40 sieve: 10
(4) Inorganic soil

Soil Type: MH

c. **Example 3.**

Given:

(1) The percent of material retained on the Number 200 sieve: 90 percent
(2) The percent of coarse material retained on the Number 4 sieve: 75 percent
(3) The well-graded coarse fraction
(4) The LL of material passing the Number 40 sieve: 40
(5) The PI of material passing the Number 40 sieve: 4

Soil Type: GW-GM

6. **<u>Conversion of Soils Classified Under Alternate Systems to the USCS</u>**. As previously mentioned, numerous soil classification systems exist. Therefore, military engineers often encounter data relating to soils that have been classified according to schemes other than the USCS. Under these circumstances, it is necessary to convert soil names from the alternate classification system to the USCS. The procedures involved in various conversions are outlined in FM 5-410 and Engineering Technical Letter (ETL)-0254.

PART C - REMOTE INTERPRETATION OF AERIAL PHOTOGRAPHY

Materials Quality Specialists (MOS 51G) are responsible for the collection as well as field and laboratory identification of soils. A complete description of the testing procedures used by 51Gs for soil identification is given in TM 5-330. The Terrain Analyst (MOS 81Q) is responsible for the remote interpretation of soils through the use of maps, aerial photography, and/or soil

reports. Because maps and soil reports contain written information concerning various soil types, their interpretations are fairly straightforward. The interpretation of aerial photographs, on the other hand, is generally more difficult. Therefore, the procedures that should be followed in analyzing aerial photography are discussed in the following paragraphs.

1. **Analysis of Tone**. The various objects that comprise a geographic region exhibit their own unique colors and textures, resulting in characteristic light reflectances. For example, coarse, well-drained materials or materials in arid regions tend to be very light (almost white) in tone, whereas fine-grained materials with poor drainage tend to be represented by gray tones. Dark gray to black tones are associated with fine-grained materials containing large amounts of organics and/or very high moisture contents.

Uniformity of tone is an important aid to the photo interpreter. Uniform soil conditions usually exhibit uniform tone, while nonuniform soil conditions normally result in mottled or mixed tones.

Although photographic tone is an important consideration, it should be noted that tone is affected by several factors, such as the relationship between the sun, the object, and the camera; the type of film used; the length of exposure; and the procedures allowed during processing. Therefore, it is difficult to develop standard values for tonal variations. This allows for the subjective interpretation of aerial photographs. In fact, the same tones and patterns are frequently perceived and interpreted differently by different analysts. Obviously, care should be taken in using tone as a photo-interpretive element.

2. **Analysis of the Effects of Erosion**. The erosional patterns evident on an aerial photograph are the result of the actions of wind, water, and/or ice. As previously mentioned, gullies are erosional features that are particularly useful in the determination of soil textures. A discussion of the way in which soil types may be determined through interpretation of gully profiles is given in Lesson 2.B.1.a.(1)(a) page 2-4. In order for gully analysis to be useful as a photo-interpretive key, the scale of the photograph must be sufficiently large-generally 1:20,000 or larger. In areas where soil cover is easily observed, such as in arid or semiarid regions, interpretation tends to be more reliable.

3. **Analysis of Drainage**. The drainage patterns and textures present on aerial photographs are possible indicators of the origin, composition, and type of underlying soil, as described in Lesson 2.B.1.a.(1)(b) page 2-4. Drainage is often considered to be the single most important photo-interpretive feature because of the ease with which stream courses may be detected and delineated on aerial photographs.

4. **Analysis of Topography**. Through the use of aerial photography, terrain analysts may determine the relative elevations of various areas of the topographic surface, thereby gaining information concerning the types of materials present in those areas. As discussed in Lesson 1, ridges existing in humid regions underlain by sedimentary rocks are normally composed of sandstone, whereas the valleys are often made up of limestone or shale. As a result, fairly coarse-grained soils, which form from the weathering of sandstone, are generally encountered on or near ridges, while clays or silts are usually found in valleys where limestone or shale has undergone weathering.

The analyst may also qualitatively describe the erosional or depositional landforms of an area. As discussed in Lesson 2, once the landforms have been identified, the types of materials most likely comprising them may be determined. For example, a point bar is generally composed of sand- to gravel-sized particles, whereas a floodplain consists mainly of clay- and silt-sized material.

5. **Analysis of Vegetation**. Although climate strongly controls the overall vegetation of a particular region, the chemistry and structure of a soil, as well as its moisture content, also exert an influence on the type of vegetation encountered. In a given climate, if only one type of vegetation is dominant, the underlying soil is probably homogeneous. On the other hand, if the vegetation prevailing in one area can be distinguished from that of another, the two areas are probably underlain by different soil types. As a photo-interpretive key, vegetation is employed mainly as a rough guide to indicate the broad variability of soil types within a specific region.

In addition, the type of vegetation present in an area may also be used as a crude indication of the underlying soil type. For example, deciduous trees, with their spreading root systems, have a competitive advantage in areas underlain by cohesive, day-rich soils. Coniferous trees, on the other hand, contain primary tap roots and are best suited for areas underlain by well-drained, sandy soils.

6. **Analysis of Land Use**. Land-use patterns can be additional indicators of underlying soil conditions. For example, croplands are generally composed of relatively fine-grained soils, whereas transportation networks and urban areas are normally sited on well-drained, relatively coarse materials. Such land-use factors should be taken into account when analyzing aerial photographs.

7. **Analysis of Pattern**. The combination of tone, erosional effects, drainage, landforms, vegetation, and land use make up the pattern of an aerial photograph. Similar soils that are derived from the same type of parent material, deposited in similar fashions, and occupy similar topographic positions will, under the same environmental conditions, usually exhibit similar photographic patterns. Dissimilar soils, on the other hand, are represented by dissimilar patterns.

8. **Analysis of Geography**. The physical geography of an area is the result of its geologic history and the prevailing climatic conditions, as manifested through the combination and arrangement of erosional characteristics, drainage features, topographic landforms, vegetational occurrences, and land-use patterns. Successful interpretation of the geography of a region often leads to the relatively accurate classification of soils.

PART D - RECORDING REMOTELY SENSED SOIL INFORMATION

Soil information derived from remote interpretation is recorded graphically as a soil factor overlay (see figure 3-7). Table 3-2, page 3-20, contains tabular information regarding the properties of individual soil units depicted in figure 3-7.

Preparing a soil factor overlay and its associated soil data table includes the following procedures:

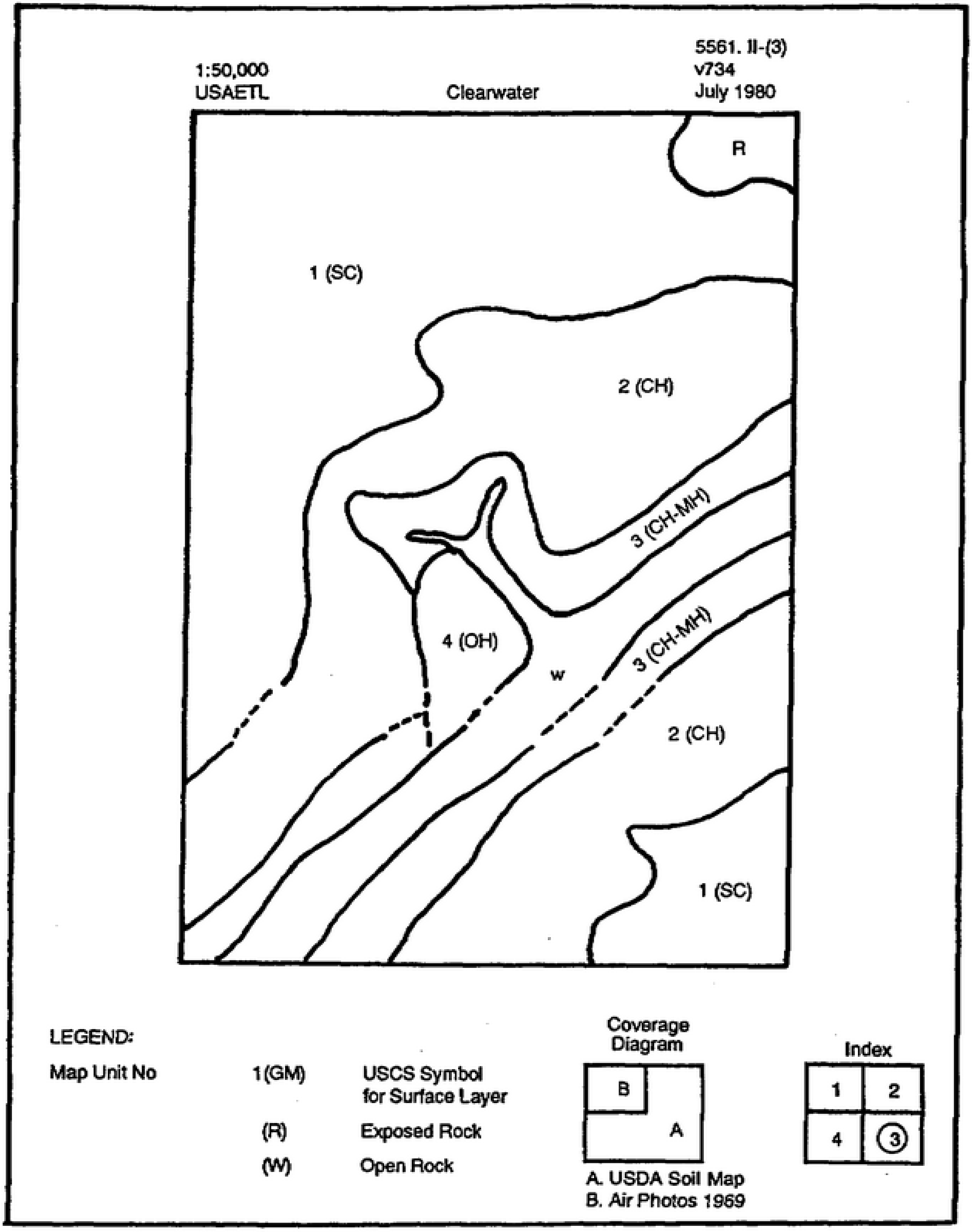

Figure 3-7. Sample soil factor overlay

Table 3-2. Sample soils data table

Map Unit Number	Soil Profile			Depth to Electrock	State of Ground												Stoni-ness	RCI		Remarks
	Horizon	Depth	USCS Symbol	M	J	F	M	A	M	J	J	A	S	O	N	D	%	Wet	Dry	
1	A B C	0-3 3-9 9-12	SC SM SM	12	S	S	S	F	M	W	D	D	D	M	W	F	0	82T	100T	These data are based on field sampling.
2	A B C	0-15 15-9 9-12	CH SC SP	17	S	S	S	F	M	W	D	D	D	M	W	F	5	95 80 NA	110 102 NA	Stoniness varies; lower elevations tend to be stonier.
3	A B C	0-5 5-9 9-18	CH-MH MH	18	S	S	S	F	M	W	D	D	D	M	W	F	15	85 85 85	150 130 130	
4	—		OH		S	S	S	F	M	W	D	D	D	M	W	F	0	35	NA	

1. **Collection of Information**. The first step in preparing a soil-factor overlay and its associated soil data table involves the collection of available source materials, such as soil maps, landform distribution map, geologic maps, topographic maps, aerial photographs, and field investigation reports.

2. **Examination of Materials**. The information that has been collected must then be examined to ensure that it is up-to-date, accurate, and reliable. Any material that fails to meet these criteria should be ignored in further analyses.

3. **Analysis of Data**. The remaining data must be consolidated and analyzed so that soil types may be determined.

4. **Delineation of Boundaries**. The boundaries of the various soil polygons should be delineated on a sheet of mylar that has been placed over and registered to the 1:50,000 or larger scale topographic map(s) covering the area of interest.

5. **Labeling of Polygons**. Each soil's polygon delineated within the area of interest should be labeled with a unique number followed by its USCS abbreviation for soil type in parentheses.

6. **Creation of a Legend**. A legend must be created and included in the margin of the soil overlay.

7. **Recording of Tabular Data**. The number assigned to each of the soil polygons is recorded in the soil data table along with corresponding information regarding the soil profile, the state of the ground, the stoniness of the soil, and the soil's rating cone index (RCI), to be discussed later.

8. **Storage and Retrieval of Information**. The soil factor overlay and its associated soil data table are stored together in a data base in such a way that they may be quickly and easily retrieved and used as needed.

PART E - APPLICATION OF SOIL INFORMATION

Information concerning the soil types of a region may be used to estimate the general engineering properties and trafficability characteristics of the soils.

1. **General Engineering Properties**. Each category within the USCS consists of a specific soil type exhibiting its own unique engineering properties.

a. **Well-Graded Gravel**. Well-graded gravels display the following engineering characteristics:

(1) Drainage: Excellent
(2) Compressibility/expansion: Negligible
(3) Permeability when compacted: Pervious
(4) Shear strength when compacted and saturated: Excellent
(5) Potential frost action: None to very slight
(6) Value as a construction material: Excellent

b. **Poorly Graded Gravel**. Poorly graded gravels display the following engineering characteristics:

(1) Drainage: Excellent
(2) Compressibility/expansion: Negligible
(3) Permeability when compacted: Very pervious
(4) Shear strength when compacted and saturated: Good
(5) Potential frost action: None to very slight
(6) Value as a construction material: Good

c. **Silty Gravel**. Silty gravels display the following engineering characteristics:

(1) Drainage: Fair to nearly impervious
(2) Compressibility/expansion: Very slight to slight
(3) Permeability when compacted: Semipervious to impervious
(4) Shear strength when compacted and saturated: Good
(5) Potential frost action: Slight to moderate
(6) Value as a construction material: Good

d. **Clayey Gravel**. Clayey gravels display the following engineering characteristics:

(1) Drainage: Poor to nearly impervious
(2) Compressibility/expansion: Slight
(3) Permeability when compacted: Impervious
(4) Shear strength when compacted and saturated: Good to fair
(5) Potential frost action: Slight to moderate
(6) Value as a construction material: Good

e. **Well-Graded Sand**. Well-graded sands display the following engineering characteristics:

(1) Drainage: Excellent
(2) Compressibility/expansion: Negligible
(3) Permeability when compacted: Pervious
(4) Shear strength when compacted and saturated: Excellent
(5) Potential frost action: None to very slight
(6) Value as a construction material: Excellent

f. **Poorly Graded Sand**. Poorly graded sands display the following engineering characteristics

(1) Drainage: Excellent
(2) Compressibility/expansion: Negligible
(3) Permeability when compacted: Pervious
(4) Shear strength when compacted and saturated: Good
(5) Potential frost action: None to very slight
(6) Value as a construction material: Fair

g. **Silty Sand**. Silty sands display the following engineering characteristics:

(1) Drainage: Fair to nearly imperious
(2) Compressibility/expansion: Very slight to moderate
(3) Permeability when compacted: Semipervious to impervious
(4) Shear strength when compacted and saturated: Good
(5) Potential frost action: Slight to high
(6) Value as a construction material: Fair

h. **Clayey Sand**. Clayey sands display the following engineering characteristics:

(1) Drainage: Poor to nearly impervious
(2) Compressibility/expansion: Slight to moderate
(3) Permeability when compacted: Impervious
(4) Shear strength when compacted and saturated: Good to fair
(5) Potential frost action: Slight to high
(6) Value as a construction material: Good

i. **Silt With Low Plasticity**. Silts with low plasticity display the following engineering characteristics:

(1) Drainage: Fair to poor
(2) Compressibility/expansion: Slight to moderate
(3) Permeability when compacted: Semipervious to impervious
(4) Shear strength when compacted and saturated: Fair
(5) Potential frost action: Moderate to very high
(6) Value as a construction material: Fair

j. **Clay With Low Plasticity**. Clays with low plasticity display the following engineering characteristics:

(1) Drainage: Nearly impervious
(2) Compressibility/expansion: Moderate
(3) Permeability when compacted: Impervious
(4) Shear strength when compacted and saturated: Fair
(5) Potential frost action: Moderate to high
(6) Value as a construction material: Good to fair

k. **Organics With Low Plasticity**. Organics with low plasticity display the following engineering characteristics:

(1) Drainage: Poor
(2) Compressibility/expansion: Moderate to high
(3) Permeability when compacted: Semipervious to impervious
(4) Shear strength when compacted and saturated: Poor
(5) Potential frost action: Moderate to high
(6) Value as a construction material: Fair

l. **Silt With High Plasticity**. Silts with high plasticity display the following engineering characteristics:

(1) Drainage: Fair to poor
(2) Compressibility/expansion: High
(3) Permeability when compacted: Semipervious to impervious
(4) Shear strength when compacted and saturated: Fair to poor
(5) Potential frost action: Moderate to very high
(6) Value as a construction material: Poor

m. **Clay With High Plasticity**. Clays with high plasticity display the following engineering characteristics:

(1) Drainage: Nearly impervious
(2) Compressibility/expansion: High
(3) Permeability when compacted: Imperious
(4) Shear strength when compacted and saturated: Poor
(5) Potential frost action: Moderate
(6) Value as a construction material: Poor

n. **Organics With High Plasticity**. Organics with high plasticity display the following engineering characteristics:

(1) Drainage: Nearly imperious
(2) Compressibility/expansion: High
(3) Permeability when compacted: Impervious
(4) Shear strength when compacted and saturated: Poor
(5) Potential frost action: Moderate
(6) Value as a construction material: Poor

o. **Peat**. Peat displays the following engineering characteristics:

(1) Drainage: Fair to poor
(2) Compressibility/expansion: Very high
(3) Permeability when compacted: Impervious
(4) Shear strength when compacted and saturated: Poor
(5) Potential frost action: Slight
(6) Value as a construction material: Poor

2. **Trafficability**. The term trafficability, if used in the general sense, refers to the overall suitability of terrain for the cross-country movement of military forces. However, the emphasis in this course is placed on soil trafficability, which is a measure of the capacity of a soil to support vehicular movement.

a. **Qualitative Estimations of Soil Trafficability**. Qualitative estimations concerning soil trafficability may be made based on the gradational characteristics of the soil as well as the soil type.

(1) **Gradational Characteristics**. The trafficability of a soil is significantly affected by the soil's gradational characteristics. Poorly graded soils tend to exhibit loose soil structures because of the large amount of void space that exists between individual particles within the soil mass (see figure 3-8).

In contrast, because well-graded materials are composed of a relatively uniform distribution of a wide range of particle sizes, the spaces surrounding large grains may become filled with smaller grains, creating what is called an interlocking soil structure (see figure 3-9, page 3-26).

Compared to the particles within a poorly graded soil, those within a well-graded soil are more closely surrounded by other particles; therefore, well-graded soils possess a higher degree of grain-to-grain contact. This increased amount of contact between grains serves to lock the soil particles into place, thereby reducing the likelihood of individual grain displacement with the application of an external load. For this reason, the trafficability of well-graded soils tends to be better than that of poorly graded ones.

(2) **Soil Type**. Because trafficability characteristics vary from one soil type to another, qualitative estimations of trafficability may be made based on the soil types present within an area.

(a) **Gravel**. In general, the trafficability of gravels is excellent for tracked vehicles; however, where gravels are pure, loose particles may roll under pressure, hampering the movement of wheeled vehicles. Weather has very little effect on the trafficability of gravel.

(b) **Sand**. Dry sand normally impedes the movement of both tracked and wheeled vehicles, especially in areas of sloping terrain. However, where sands are mixed with clay or where enough moisture is present to allow for compaction, the sand exhibits improved trafficability.

(c) **Silt**. When dry, silts usually offer excellent trafficability; however, because dry individual silt particles are very small and have little or no cohesion, conditions may become

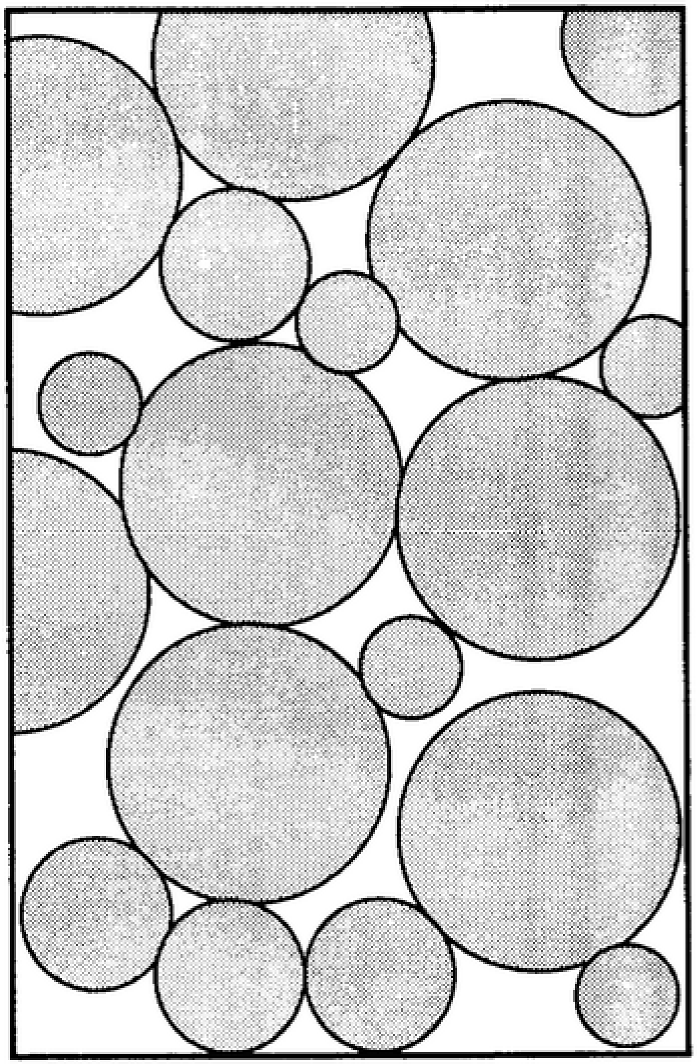

Figure 3-8. Structure of a poorly graded soil

dusty. When wet, silt particles become cohesive, forming a deep, soft mud that presents a definite obstacle to vehicular movement.

(d) **Clay**. When clays are completely dry, they are hard and provide excellent trafficability for all types of vehicles; however, clays are seldom dry except in extremely arid regions. In most areas, clays contain significant amounts of water and exhibit varying degrees of plastic behavior; therefore, the trafficability of clays is generally poor to nonexistent.

(e) **Organic Material**. Although organic material may be passable when dry, it is commonly treacherous when wet.

b. **Quantitative Determination of Soil Trafficability**. In addition to qualitative estimations of soil trafficability, quantitative determinations may also be made. Direct quantitative measurements of soil trafficability may be obtained by a 51G through the use of a soil trafficability test set; indirect quantitative estimations may be made by an 81Q through the use of remotely collected soil information. The detailed procedures involved in the

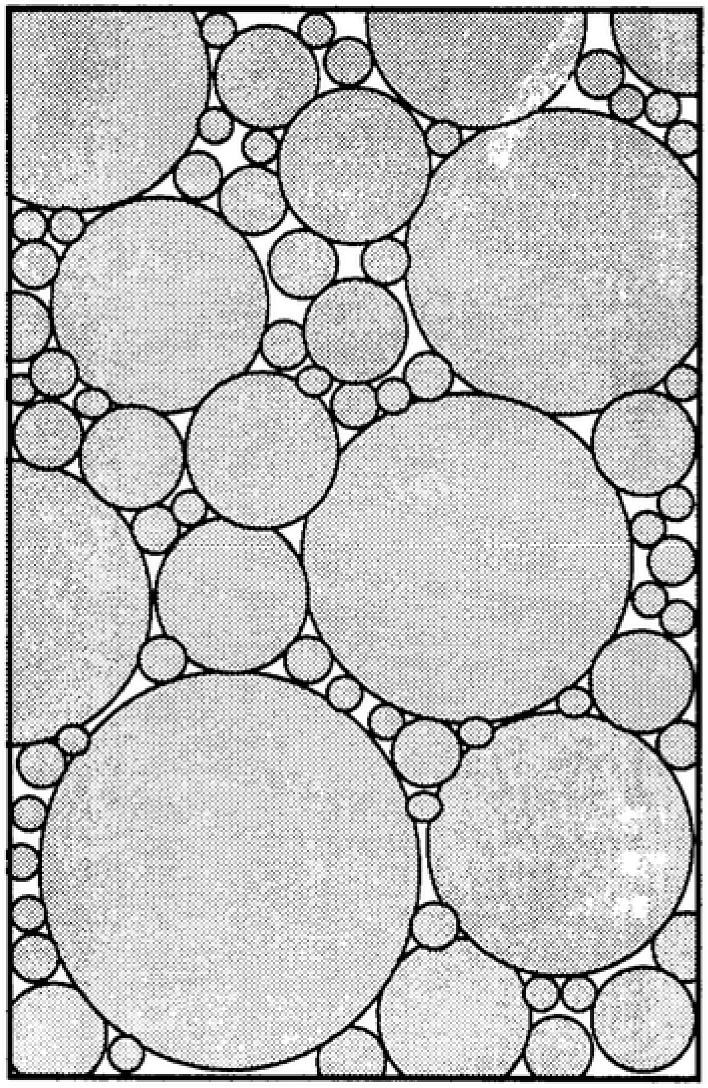

Figure 3-9. Structure of a well-graded soil

quantitative determination of soil trafficability are detailed in TM 5-330. A broad overview of those procedures is discussed in the following paragraphs.

(1) **Preliminary Information**. Before an in-depth quantitative analysis of soil trafficability can begin, some preliminary information must be considered.

(a) **Conditions for Sampling**. Ideally, field sampling of soils for trafficability purposes takes place under the soil's worst natural condition. If testing under these circumstances is not possible, then the worst trafficability condition must be extrapolated from data concerning the soil type, topography, climate, and weather.

(b) **Identification of Soil Type**. Using established field classification or remote collection techniques, existing soil types are determined according to the USCS.

(c) **Identification of Critical Layer**. The layer within a given soil profile that has the greatest impact on trafficability is called the critical layer. As shown in table 3-3, the depth

and thickness of the critical layer vary with the type and weight of the vehicle, the type of soil, and the number of pass required.

In addition, the nature of the soil profile may also influence the position of the critical layer. Within a fine-grained soil having a normal soil profile, the critical layer for one pass of a light (46,000-pound), self-propelled, full-tracked, 10-millimeter, M37 howitzer is 0 to 6 inches. The critical layer for 50 passes of the same vehicle is 6 inches to 12 inches. The critical layer must be identified before proceeding with trafficability determinations.

(d) **Sampling Density**. The total number of individual sites that must be tested in order to accurately describe the soil trafficability conditions of a given region may be determined by using the soil trafficability test site template provided in figure 3-10, page 3-28.

The number of test sites required for a questionable trafficability area is listed within the template oval that most closely approximates the size of that area as depicted at final graphic scale. Care should be taken to ensure that samples represent typical soil conditions and that selected sites serve to define soil boundaries.

(2) **Field/Laboratory Procedures**. An in-depth quantitative field analysis of soil trafficability involves the use of a soil trafficability test set (see figure 3-11, page 3-28). Where field analysis is not possible, trafficability determinations may be made based on remotely collected information.

(a) **Cone Index (CI)**. The first step in the field analysis of soil trafficability is the determination of the CI of the soil. The CI, which is an indication of the soil's shear strength,

Table 3-3. Variation of critical layer with respect to vehicle type and weight, soil type, and number of passes required.

Type and/or Weight of Vehicle	Depth of Normal Critical Layer (Inches)			
	1 Pass		50 Passes	
	Fine-Grained Soils	Coarse-Grained Soils	Fine-Grained Soils	Coarse-Grained Soils
Sleds	0 - 3	0 - 3	0 - 3	0 - 3
M116 and other tracked vehicles with ground contact pressures less than 4 psi	0 - 6	0 - 6	3 - 9	0 - 6
Wheeled, up to 50,000 lbs	0 - 6	0 - 6	6 - 12	0 - 6
Wheeled, over 50,000 lbs	3 - 9	0 - 6	9 - 15	0 - 6
Tracked, up to 100,000 lbs	0 - 6	0 - 6	6 -12	0 - 6
Tracked, over 100,000 lbs	3 - 9	0 - 6	9 -15	0 - 6

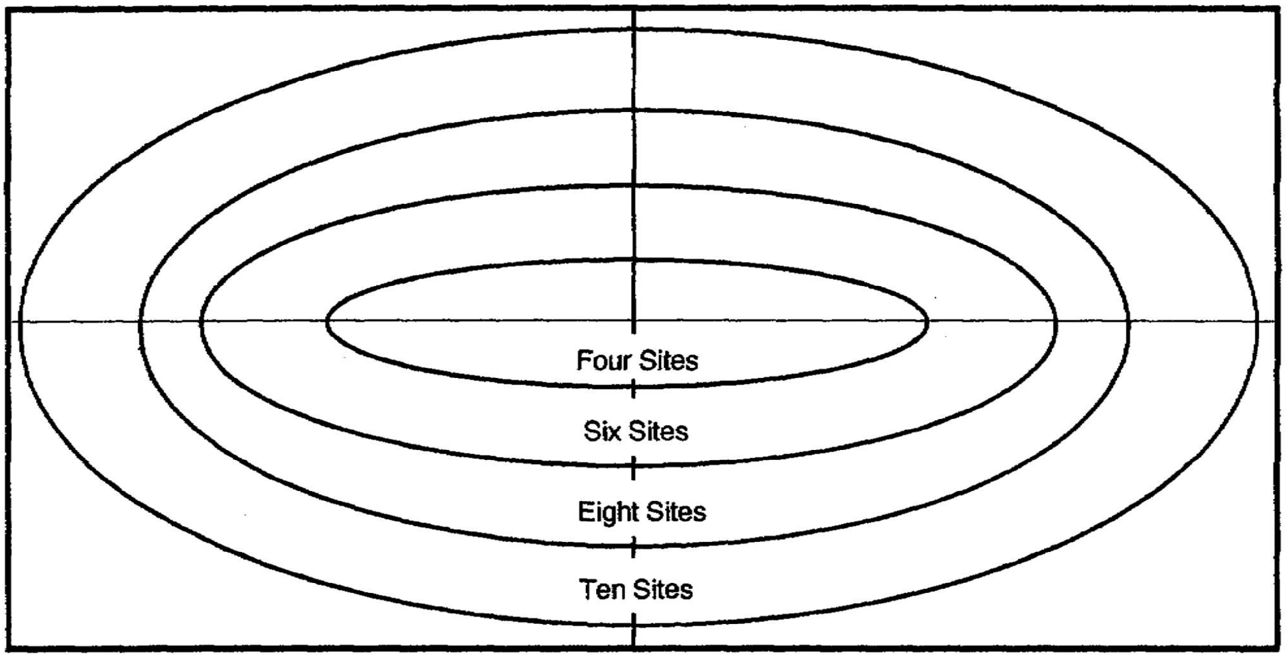

Figure 3-10. Soil trafficability test site template

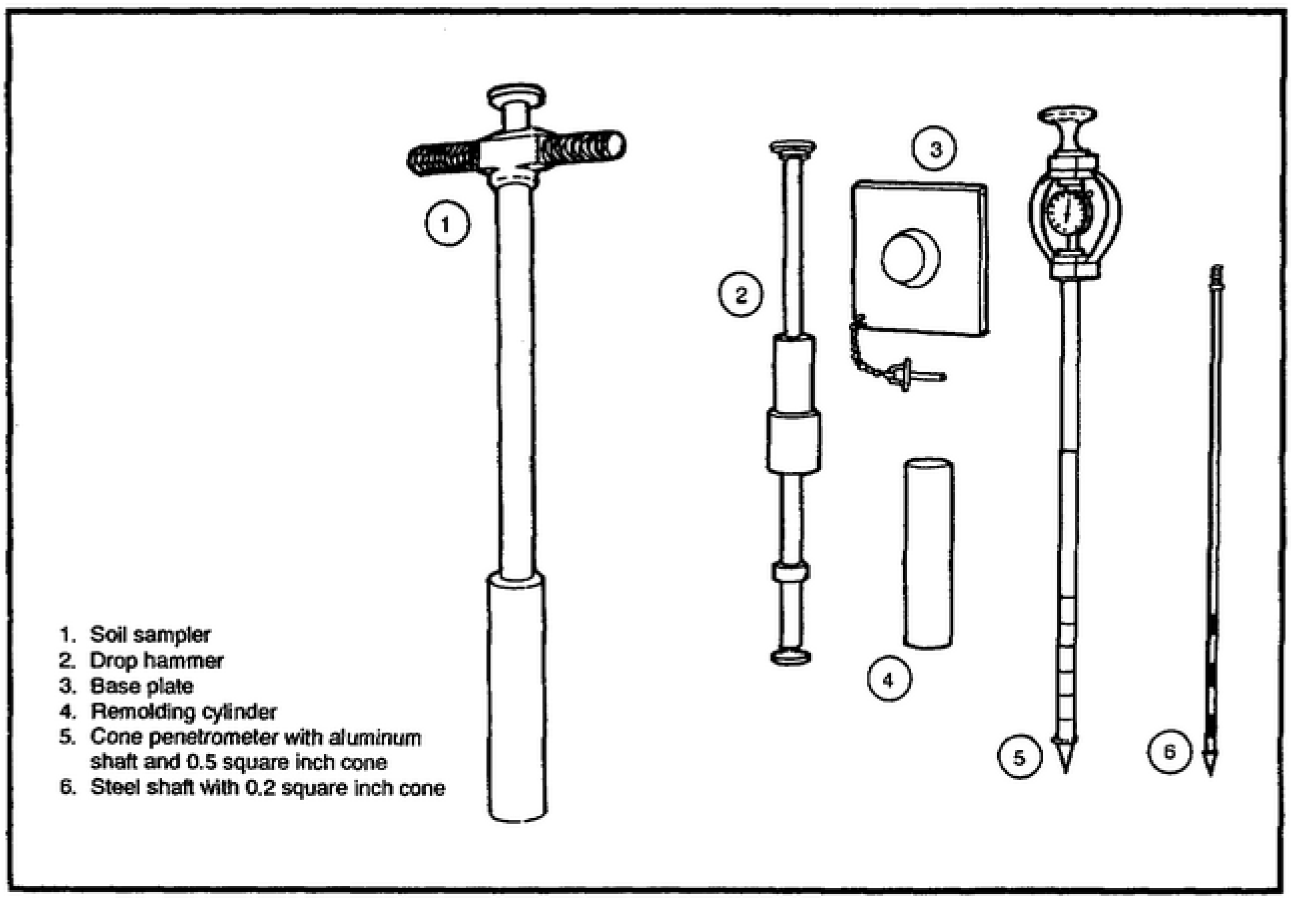

Figure 3-11. Soil trafficability test set

is measured with a cone penetrometer containing an aluminum shaft and a 30-degree cone that has an area of 0.5 square inches (see figure 3-11, page 3-28). During operation, the analyst places both hands on the handle of the instrument, with one hand on top of the other (see figure 3-12).

Next, with the shaft of the instrument in a vertical position, a slow, steady, downward force is applied. At the instant the cone base is flush with the ground, a second analyst reads the numeric value indicated on a radial dial. This value, which may range from 0 to 300, is then recorded for a depth of 0 inches on a chart similar to the one shown in table 3-4 page 3-30.

As downward movement of the cone penetrometer continues, the dial readings are recorded at successive 6-inch intervals to a depth of at least 6 inches below the critical layer of the design vehicle. It was previously determined (Lesson 3.E.2.b.(1)(c) page 3-27) that the critical layer for 50 passes of a 105-millimeter howitzer over fine-grained soil is 6 inches to 12 inches; therefore, under these circumstances, the dial readings must be recorded to a depth of 18 inches (see table 3-4, page 3-30). Following the completion of each test, the cone penetrometer is extracted by either the handle or the shaft. One the results of the required number of tests have been recorded, the individual values obtained for each test at a particular depth are

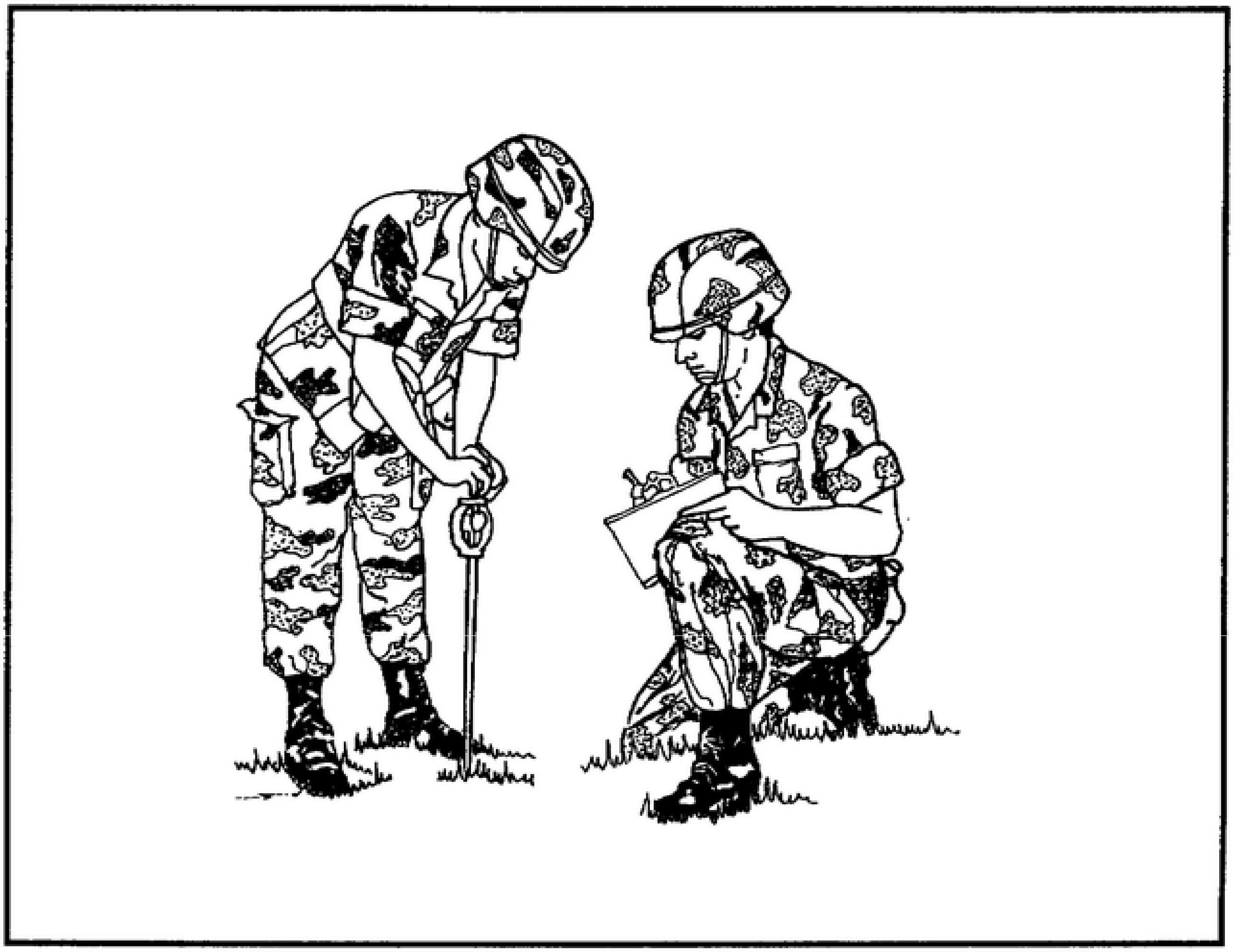

Figure 3-12. Determination of cone index

Table 3-4. Recording CI values

Trafficability Test Data					
Project Location PDG 488519			Type of Vehicle Howitzer, 105 mm		
Cone Index Values					
Test Numbers	Dial Readings at Depth				
	0 inches	6 inches	12 inches	18 inches	24 inches
1	48	56	64	70	
2	42	50	58	64	
3	41	49	57	63	
4	46	54	62	68	
5	47	53	60	66	
Average	44.8	52.4	60.2	66.2	
Normal Abnormal	49	56	63		
CI_1 = 49 CI_{50} = 56					

averaged (see table 3-4). In order to arrive at the CI of a 6-inch layer of soil, the average values of the top and bottom levels of that soil must themselves be averaged. Table 3-4 shows that the soil layer occurring at a depth of-

- 0 to 6 inches has a CI of 49 ((44.8 + 52.4/2).
- 6 inches to 12 inches has a CI of 56 ((52.4 + 60.2)/2).
- 12 inches to 18 inches has a CI of 63 ((60.2 + 66.2)/2).

Under most circumstances, the CI will increase or remain constant with depth, resulting in a normal soil profile. However, in some cases, a reversal in this trend occurs, and the soil is said to have an abnormal soil profile. The type of soil profile present in the test area is indicated on the chart of CI values (see table 3-4).

Finally, the CI value for the critical layer corresponding to one pass of the design vehicle as well as the CI value corresponding to 50 passes of the design vehicle are entered into the chart of CI values. For example, the critical layer for one pass of a 105-millimeter howitzer over fine-grained soil is 0 to 6 inches, while the critical layer for 50 passes of the same vehicle is 6 inches to 12 inches (see Lesson 3.E.2.b.(1)(c) page 3-27). Therefore, the corresponding CI values for these two layers are entered into the chart as CI_1 and CI_{50} respectively (see table 3-4).

(b) **Remolding Index (RI)**. The CI is a measurement of the shear strength of a soil in its undisturbed condition; however, except for gravels and sands containing little or no fines, soils tend to experience changes in shear strength due to the passage of traffic. In order to describe the changes that take place in fine-grained soils and remoldable sands, the RI of such soils must be calculated. The RI is the ratio of the remolded soil strength to the original soil strength.

The determination of a soil's RI begins by using a soil sampler to extract a 6-inch sample of soil from the critical layer under study (see figure 3-11, page 3-28). With the locking handle in the unlocked position, the 2-inch diameter soil sampler is pushed into the ground to a depth of 6 inches (see figure 3-13). The locking handle is then switched to the locked position, and the 6-inch soil layer is extracted from the subsurface. If the soil within the soil sampler tube was not removed from the critical layer in question, then the locking handle is unlocked and the soil sample is discarded. Progressively deeper samples are extracted until the soil filling the sampler tube is derived from the critical layer under study. It should be noted that, if or when an abnormal soil profile is encountered, samples must be extracted from both the critical layer and the 6-inch layer directly underlying the critical layer. Next, the locking handle is unlocked and pushed downward so that the sample is driven into the remolding cylinder mounted on the base plate (see figures 3-11 and figure 3-14).

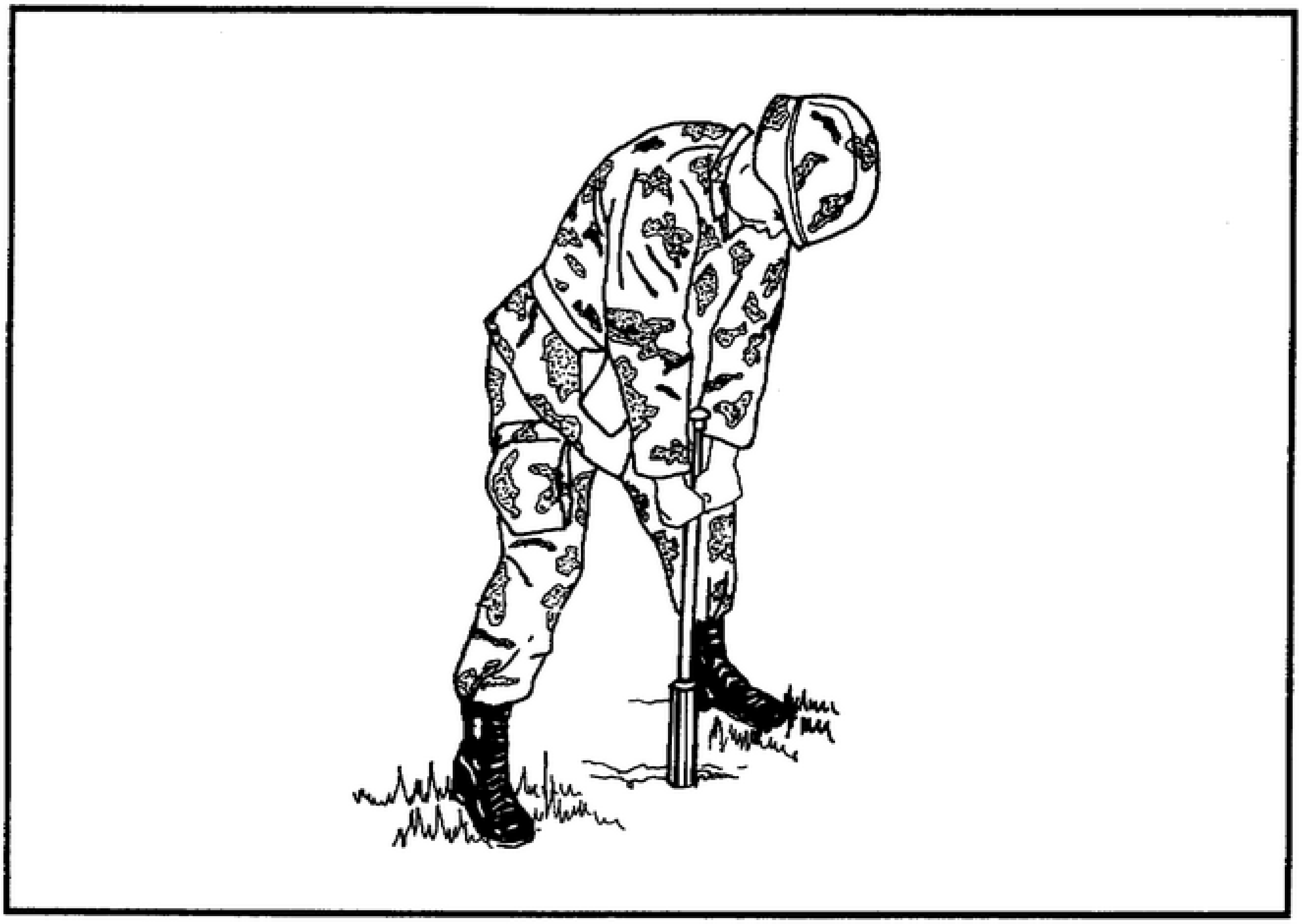

Figure 3-13. Extraction of a soil sample

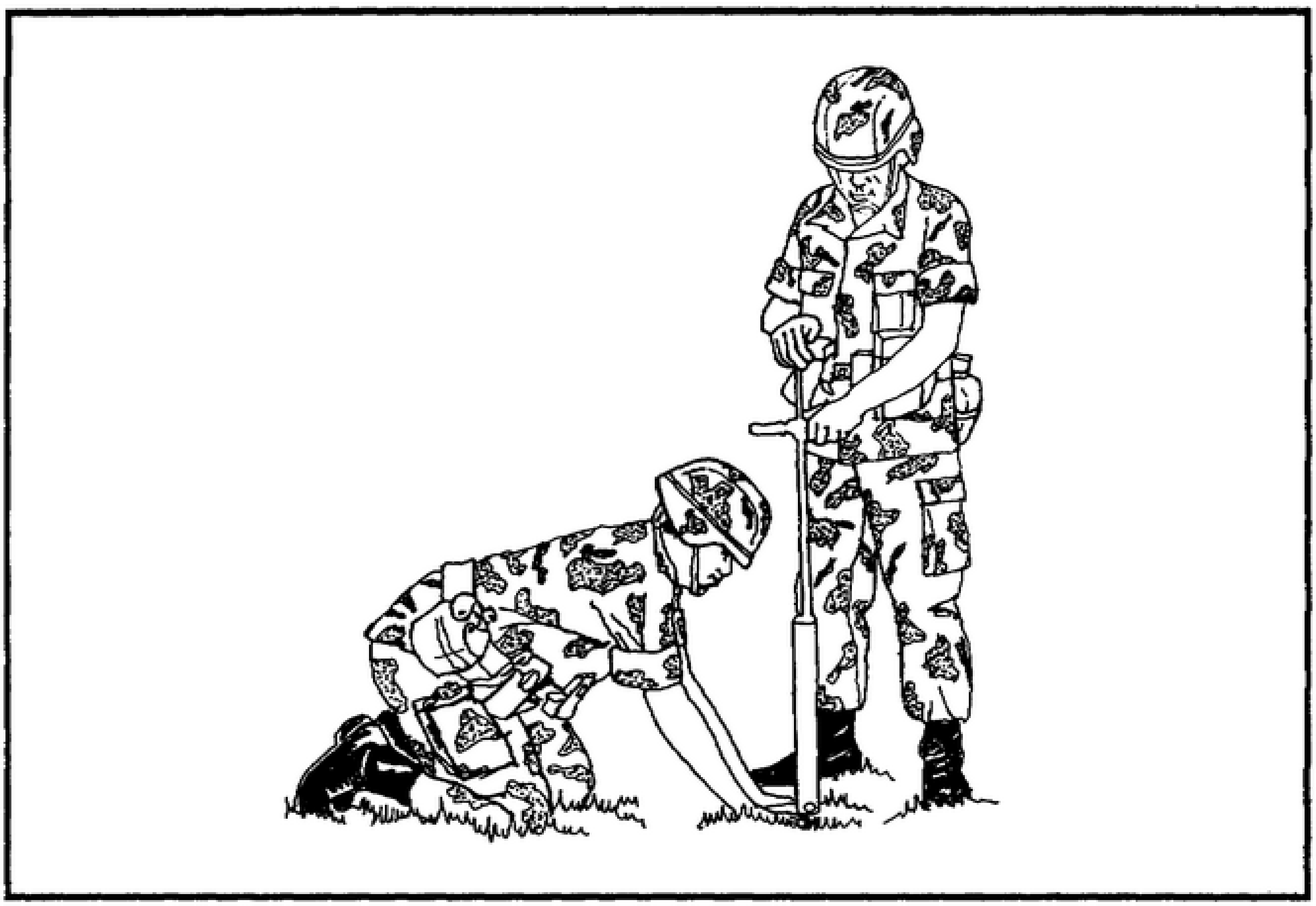

Figure 3-14. Transfer of extracted sample to remolding cylinder

The sample is then pushed to the bottom of the cylinder with the foot of the drop-hammer staff (see figure 3-11, page 3-28). This allows the analyst to determine undisturbed CI readings on the sample within the remolding cylinder. The equipment used in obtaining these CI readings varies depending on the type of soil sampled. For fine-grained soils, the equipment required consists of the cone penetrometer with an attached 5/8-inch-diameter aluminum shaft and a 30-degree cone that has a base area of 0.5 square inches. For remoldable sands, which are coarse-grained materials that contain enough fines to exhibit cohesion when wet, the equipment required consists of the cone penetrometer with an attached steel shaft and a cone that has a base area of 0.2 square inches. In either case, the procedures used are similar to those previously described for obtaining CI values, see Lesson 3.E.2.b.(2)(a) and figure 3-15). However, in this case, the dial readings are taken at 1-inch intervals for depths ranging from 0 to 4 inches. Because these values pertain to undisturbed samples, they are recorded in the "before" column of a chart similar to the one shown in table 3-5, page 3-34.

Following the determination of the undisturbed soil strength, the soil sample is remolded. Remolding procedures vary depending on the soil type. For fine-grained soils, remolding is accomplished by placing the drop-hammer foot on top of the sample in the remolding cylinder and dropping the hammer 100 times from a height of 12 inches (see figure 3-16, page 3-34). For remoldable sands, a rubber stopper is placed on top of the sample in the remolding cylinder, and the cylinder (along with the attached base plate) are dropped from a height of 6 inches onto a firm surface for a total of 25 times. Once the sample has been remolded, the analyst again determines CI readings on the soil within the remolding cylinder. The equipment and

Figure 3-15. Undisturbed CI readings on samples within the remolding cylinder

procedures used are identical to those previously described for the determination of the undisturbed strength of a soil within the remolding cylinder (see figure 3-17, page 3-35). Because the value obtained are a result of these procedure pertain to remolded soils, they are recorded in the "after" column of a chart similar to the one shown in table 3-5, page 3-34.

Once the required layers (including all critical layers as well as any layer underlying a critical layer in an abnormal soil profile) have been tested and all corresponding values have been recorded on a chart similar to the one shown in table 3-5, page 3-34, the values obtained for each test are averaged (see table 3-5, page 3-34). In order to arrive at the RI of a particular layer of soil, the average CI reading obtained for that soil while it was within the remolding cylinder following remolding is divided by the average CI reading obtained for the same soil while it was within the remolding cylinder before remolding. Referring to the soil portrayed in table 3-5, page 3-34, the RI of the soil layer occurring at a depth of 0 to 6 inches is 0.869

Table 3-5. Chart for recording remolding index values

Remolding Index Values								
	Layer 0 - 6 Inches		Layer 6 - 12 Inches		Layer		Layer	
Depth	Before	After	Before	After	Before	After	Before	After
0 Inches 1 Inches 2 Inches 3 Inches 4 Inches	57 59 62 66 71	50 53 55 57 59	54 56 59 64 67	47 50 51 53 54				
Average	63.0	54.8	60.0	51.0				
$RI = \frac{A}{B}$	$\frac{54.8}{63.0} = 0.869$		$\frac{51.0}{60.0} = 0.850$					
RI for 1 Vehicle 0.87				RI for 50 Vehicles 0.85				

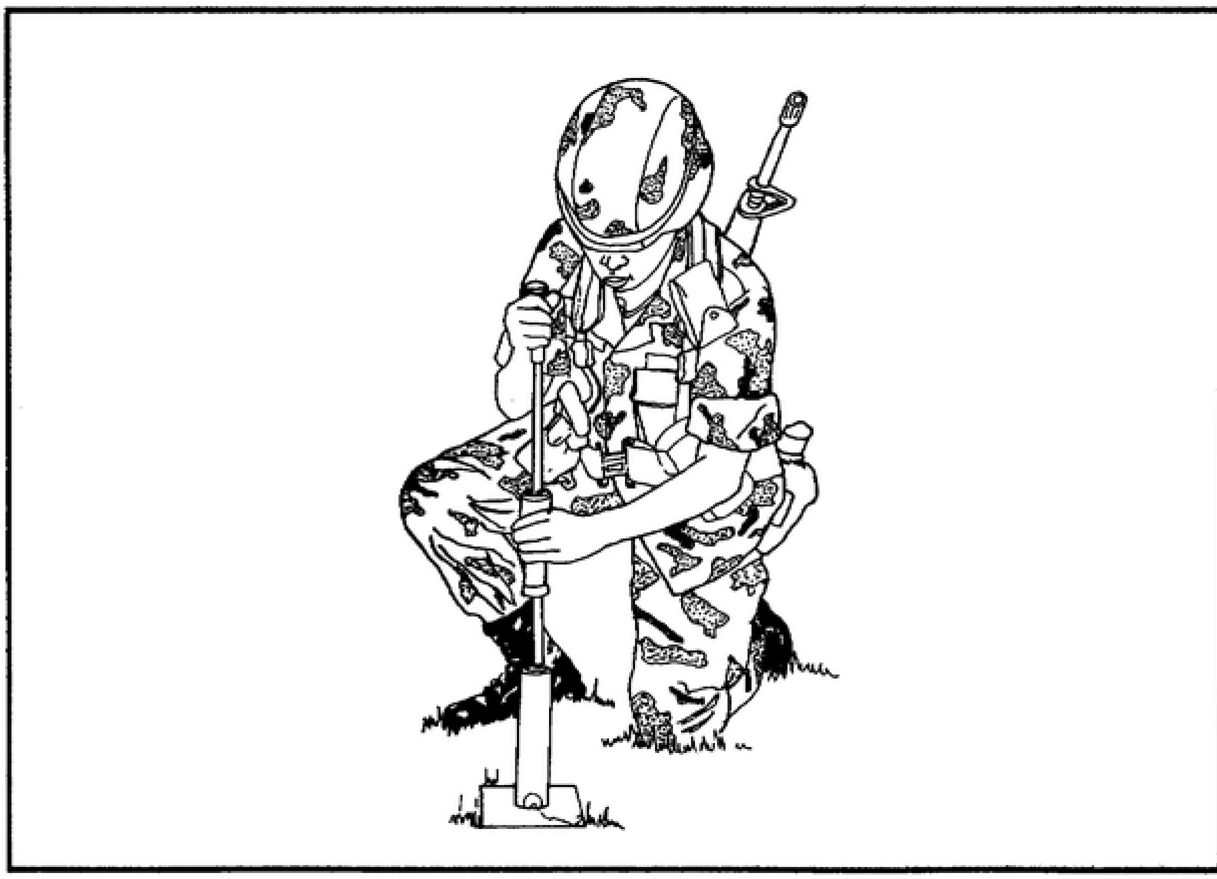

Figure 3-16. Remolding a fine-grained soil sample

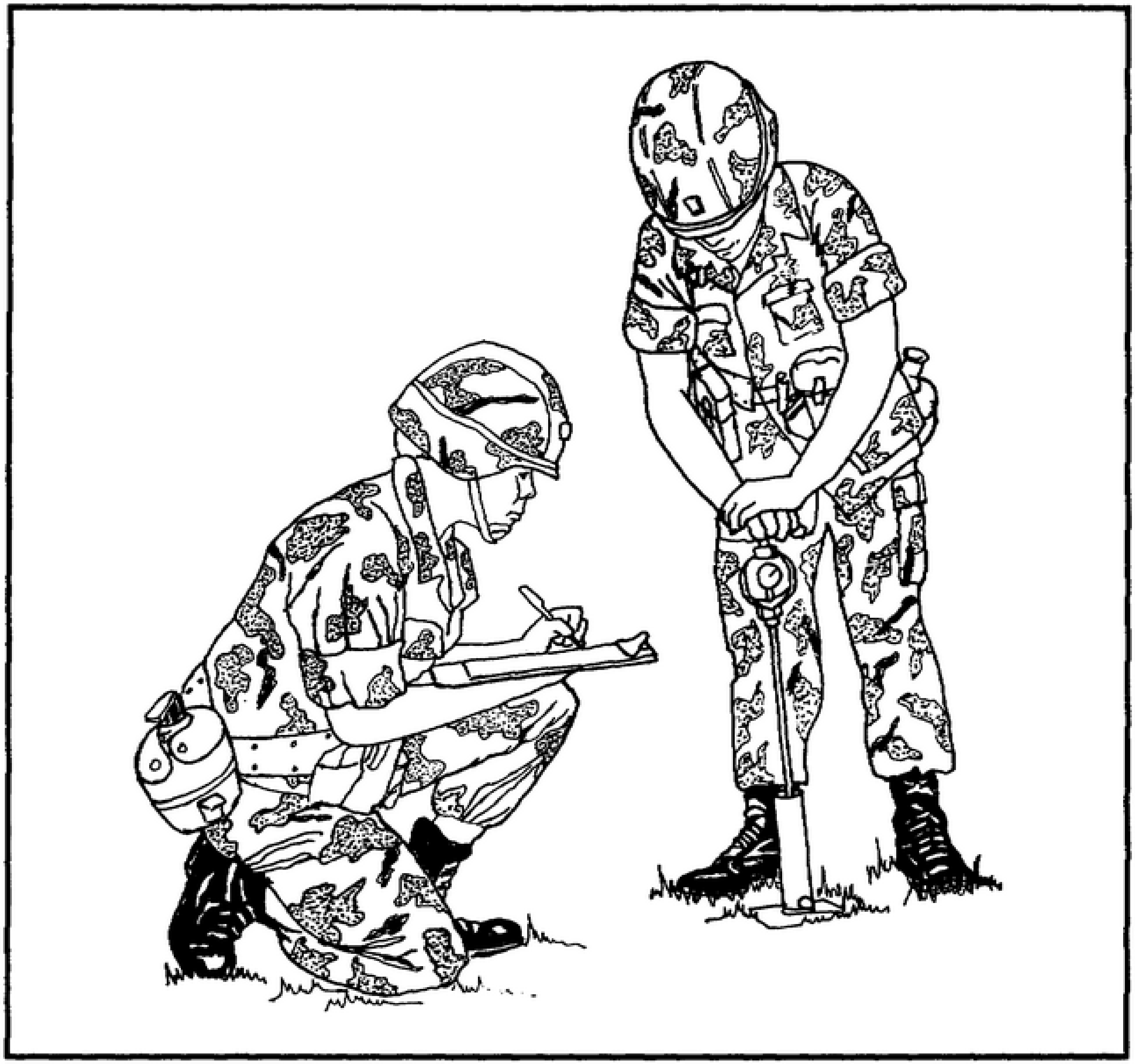

Figure 3-17. Remolded CI readings on samples within the remolding cylinder

(54.8/63.0), and the RI of the soil layer occurring as a depth of 6 inches to 12 inches is 0.850 (51.0/60.0). These values are entered into the chart as the RI for their respective soil layers.

Finally, the RI value for the critical layer corresponding to one pass of the design vehicle as well as the RI value corresponding to 50 passes of the design vehicle are entered into the chart of RI values. For example, the critical layer for one pass of a 105-millimeter howitzer over fine-grained soil is 0 to 6 inches, while the critical layer for 50 passes of the same vehicle is 6 inches to 12 inches (Lesson 3.E.2.b.(1)(c) page 3-27). Therefore, the corresponding RI values for these two layers are rounded and entered into the chart under “RI for 1 Vehicle” and “RI for 50 Vehicles” respectively (see table 3-5).

Note: Because molding tests are done only on fine-grained soils and remoldable sand other types of materials do not possess RI values.

(c) **Rating Cone Index**. The CI value for a particular layer of fine-grained soil or remoldable sand may be multiplied by the corresponding RI value to arrive at a value known as the RCI of the soil layer. For example, referring to table 3-4, page 3-30, the CI corresponding to the critical layer for one pass of a 105-millimeter Howitzer over fine-grained soil is 49. Referring to table 3-5, page 3-34, the RI for the same layer is 0.87. Therefore, the RCI for this particular layer is approximately 43 (49 x 0.87). Likewise, referring to table 3-4, page 3-30, the CI corresponding to the critical layer for 50 passes of a 105-millimeter howitzer over fine-grained soil is 56. Referring to table 3-5, page 8-34, the RI for the same layer is 0.85. Therefore, the RCI for this particular layer is approximately 48 (56 x 0.85). These two values are entered into a composite chart, such as the one shown in figure 3-18, as RCI_1 and RCI_{50} respectively.

Because materials other than fine-grained soils and remoldable sands do not possess RI values, their RCI values cannot be calculated.

When extensive field investigations for the determination of soil trafficability conditions are not practical, 81Qs often use charts to quantitatively estimate RCI values for known soil types under various environmental conditions (see table 3-6, page 3-38).

Although gravels containing appreciable amounts of fine material are not subjected to field remolding tests, they may experience changes in shear strength due to the passage of traffic. Consequently, RCI values for these types of soils have also been included in the charts based on estimations made from organic, textural, and plastic properties exhibited under given moisture conditions.

(d) **Vehicle Cone Index (VCI)**. The VCI is a value assigned to a given vehicle for a given number of passes (1 or 50). Table 3-7, pages 3-40 through 3-46, contains the VCI values for numerous types of military vehicles. Once the VCI values for a particular type of vehicle have been determined, they are entered into a composite chart (see figure 3-18). For example, the VCI for one pass of a 105-millimeter howitzer is 21, and the VCI for 50 passes of a 105-millimeter howitzer is 49. Therefore, these values are entered into the chart as VCI_1 and VCI_{50} respectively.

(e) **Comparison of Cone Index or Rating Cone Index to Vehicle Cone Index**. The final step in determining the trafficability of a soil on level terrain with respect to a specific type of vehicle is the comparison of the CI value (in the case of coarse-grained materials containing little or no fines) or the RCI value (in the case of fine-grained soils or remoldable sands) with the VCI value obtained for the corresponding critical layer. In general, if the VCI for a critical layer exceeds the corresponding CI or RCI (whichever is appropriate), the soil is not trafficable for the specified number of passes of that particular vehicle. If, on the other hand, the appropriate CI or RCI value exceeds the VCI value for a particular critical layer, the soil is considered to be trafficable under the prescribed circumstances. The trafficability of the soil under question is recorded on a composite chart (see figure 3-18). For example, when the RCI of the critical layer for one pass of a 105-millimeter howitzer over the fine-grained soil sample depicted on the chart in figure 3-18 (43) is compared to the VCI for one pass of that vehicle (21), it is evident that the RCI is greater. Therefore, this particular soil is capable of supporting the movement of one 105-millimeter howitzer. However, when the same comparison is made for the critical layer representing 50 passes of the vehicle, it can be seen that the VCI (49) is greater than the RCI (48). Therefore, this soil will not support the

TRAFFICABILITY TEST DATA

1. TEST LOCATION/DATE/TIME	2. TYPE OF VEHICLE/WEIGHT
PDG 488519	Howitzer, 105 mm

3. CONE INDEX (CI) VALUES

a. TEST NUMBERS	b. DIAL READINGS AT DEPTH 0"	6"	12"	18"	24"
1	48	56	64	70	
2	42	50	58	64	
3	41	49	57	63	
4	46	54	62	68	
5	47	53	60	66	
AVERAGE	44.8	52.4	60.2	66.2	

NORMAL ABNORMAL	49	56	63	

c. CI_1 = 49

d. CI_{50} = 56

e. CRITICAL LAYER FOR 1 VEHICLE	f. CRITICAL LAYER FOR 50 VEHICLES
0–6"	6–12"

4. REMOLDING INDEX (RI) VALUES

	a. LAYER 0–6"		LAYER 6–12"		LAYER		LAYER	
b. DEPTH	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
0"	57	50	54	47				
1"	59	53	56	50				
2"	62	55	59	51				
3"	66	57	64	53				
4"	71	59	67	54				
c. AVERAGE	63.0	54.8	60.0	51.0				
d. RI = $\frac{\text{After}}{\text{Before}}$	$\frac{54.8}{63.0}$ = 0.869		$\frac{51.0}{60.0}$ = 0.850					

e. RI FOR 1 VEHICLE	f. RI FOR 50 VEHICLES
0.87	0.85

g. RATING CONE INDEX (RCI)

$RCI_1 = CI_1 \times RI_1$ = 49 x 0.87 = 43

$RCI_{50} = CI_{50} \times RI_{50}$ = 56 x 0.85 = 48

h. SOIL CONDITION *(Describe)* Moist

i. WEATHER CONDITIONS *(Describe)* Fair

j. VEHICLE CONE INDEX (VCI)

VCI_1 = 21 /CG CI $\geq$ VCI

VCI_{50} = 49 /FG & RS RCI $\geq$ VCI

k. TYPE OF SOIL *(Check one)*	X	FG		CG
l. SOIL STRENGTH PROFILE *(Check one)*	X	NORMAL		ABNORMAL

WILL 1 VEHICLE PASS? *(Check one)*	X	YES		NO
WILL 50 VEHICLES PASS? *(Check one)*		YES	X	NO

5. TESTED BY	6. COMPUTED BY	7. CHECKED BY
PVT Snodgrass	C.E.P.	P.H.L.

DD Form 2641, AUG 93

Figure 3-18. Sample composite soil trafficability reporting chart

Table 3-6. Probable range and means of RCI values for soils under various environmental conditions

Soil Type Symbol	RCI (Probable Range)	RCI (Mean)
High Topography, Wet Season Condition		
GW, GP		
SW, SP		
SP-SM	196-316	256
GM		230*
SM	137-287	212
CH	158-210	184
GC		165*
SC	104-208	156
MH	64-160**	112**
CL	82-180	131
SM-SC	65-211	138
ML	67-189	128
CL-ML	54-136	95
Low Topography, Wet Season Condition		
GW, GP		
SW, SP		
SP-SM	282	282*
CH	81-193	137
GC		130*
SC	61-255**	158**
SM-SC	72-208**	140**
MH	48-162	105
GM		125*
SM	34-188	111
CL	46-146	96
ML	34-134	84
CL-ML	34-96	65
OL	41-89	65
OH	14-110	62
Pt	41-51**	46**
Low Topography, High Moisture Condition		
GW, GP		
SW, SP		
CH	48-146	97
GC		90*
SC		88*
SM-SC	66-98**	82**
MH	43-123	83
CL	39-117	78
SP-SM		74*
GM		72*
SM	12-126	69
ML	22-88	55
CL-ML	26-66	46
OL	49**	49**
OH	21-49	35
Pt	41-51**	46**

Notes:
* Estimated from textural, plastisticity, and organic properties of soil under a given moisture condition.
** Based on analysis of less than five samples.

movement of fifty 105-millimeter howitzers. These results are entered into the composite chart.

Many of the manual procedures outlined for the determination of soil trafficability have been computerized so that for certain geographic regions where soil data bases exist, information may be obtained through the use of various software packages.

(3) **Presentation of Information**. Once the soil trafficability information for a particular area has been compiled, it is normally presented as an overlay or overprint to a topographic map. Alternatively, soil trafficability information may be presented in textual form and in briefing. Whenever possible, the text or briefing should include graphic material.

c. **Additional Factors Affecting Soil Trafficability**. Although the properties of stickiness and slipperiness are not included in a quantitative evaluation of soil trafficability, these parameters do influence the movement of traffic over some soils in certain instances.

(1) **Stickiness**. Stickiness is an unfavorable characteristic of some cohesive soils that can result in the adherence of the soil to the running gears of vehicles. Under extreme conditions, sticky soils may cause difficulty in steering and travel. The effects of stickiness are not measured and are not presented on cross-country movement graphics.

(2) **Slipperiness**. Slipperiness is an adverse condition that may hamper the steering of tracked vehicles or immobilize wheeled vehicles. The condition may be caused by the presence of excess water, the existence of a layer of soft, plastic soil overlying a firm layer of soil, or the occurrence of wet vegetation. The slipperiness of ground cover is not depicted on cross-country movement graphics.

d. **Other Factors Influencing General Trafficability (Cross-Country Movement)**. A complete analysis of the general trafficability of an area includes information regarding not only soil trafficability but also slopes, vegetation, and natural and man-made obstacles. Explanations concerning the influence of these other factors on trafficability are contained in TM 5-330 and FM 5-33.

Table 3-7. VCI values for selected military vehicles

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Amphibious Vehicles			
Assault vehicle, full-tracked, amphibious: M733, FSN 2320-999-4312	10.5	8	20
Carrier, cargo, amphibious, tracked: M116	10.9	7	18
Landing vehicle, tracked: MK4	36.4	19	45
Landing vehicle, tracked, armored: MK4	40.0	20	49
Landing vehicle, tracked, engineer: M1 (LVTE1)	97.5	20	49
Landing vehicle, tracked, command: M5 [LVTP5A1 (CMD)]	97.5	20	49
Landing vehicle, tracked, personnel: M5 (LVTP5A1)	87.8	19	45
Landing vehicle, tracked, howitzer: M6 (LVTH6A1)	86.6	19	45
Landing vehicle, tracked, recover: M1 (LVTR1A1)	82.2	19	44
Tank, combat, full-tracked; counterinsurgency, amphibious, lightweight: M729, FSN 2350-921-5564	10.5	8	20
Armored Bulldozers			
Bulldozer, earthmoving: M6, tank-mount (tank, combat, 90-mm gun: M47)	107.8	25	57
Bulldozer, earthmoving: M8 (tank, combat, 90-mm gun: M48)	107.8	22	50
Bulldozer, earthmoving tank-mounted: M9 (tank, combat, 105-mm gun: M60 and M60A1)	116.0	23	53
Combat Vehicles	33.6	14	32
Armored reconnaissance airborne assault vehicle (General Sheridan): M551			
Flamethrower, self-propelled:	23.3	17	40
M132	23.9	17	40
M132A1			
Gun, antiaircraft artillery, self-propelled,			
twin 40-mm:	41.2	20	48
M19A1	49.5	15	36
M42	49.5	15	36
M42A1	96.0	20	47
Gun, field artillery, self-propelled, 155-mm:			
M53 (T97)	15.5	10	24
Gun, antitank, self-propelled, 90-mm: M56	62.1	21	50
Gun, field artillery, self-propelled, 175-mm: M107 (T235E1)			

Table 3-7. VCI values for selected military vehicles (continued)

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Combat Vehicles (cont)			
Howitzer, heavy, self-propelled, full-tracked: 8-inch, M55 (T108)	98.0	20	47
Howitzer, heavy, self-propelled: 8-inch M110 (T236E1)	58.5	20	47
Howitzer, light, self-propelled, full-tracked: 105-mm, M37	46.0	21	49
Howitzer, light, self-propelled, full-tracked: 105-mm:			
M52	53.0	15	37
M52A1	53.0	15	37
Howitzer, light, self-propelled: 105-mm, M108 (T195E1)	46.9	19	45
Howitzer, medium, self-propelled, full-tracked: 155-mm:			
M44	64.0	14	32
M44A1	64.0	14	32
Howitzer, medium, self-propelled: 155-mm, M108 (T195E1)	52.5	25	57
Mortar, infantry, self-propelled, full-tracked: 107-mm (4.2-inch), M84	47.1	15	37
Rifle, self-propelled, full-tracked, multiple: 106-mm, M50	19.0	11	27
Tank, combat, full-tracked: 76-mm gun:			
M41	51.8	17	40
M41A1	51.8	17	40
M41A2	51.8	17	40
M41A3	51.8	17	40
Tank, combat, full-tracked: 90-mm gun:			
M47	101.8	24	55
M48	99.0	20	47
M48C	99.0	20	47
M48A1	104.0	21	49
M48A2	105.0	21	49
M48A2C	105.0	21	49
M48A3 (M48A1E2)	104.0	21	49
Tank, combat, full-tracked: 105-mm gun:			
M60	102.0	20	48
M60A1	102.0	20	48
Tank, combat, full-tracked, 120-mm gun:			
M103	125.0	24	56
M103A1	125.0	24	56
Tank, combat, full-tracked, flame-thrower: M67A1	105.8	23	53

Table 3-7. VCI values for selected military vehicles (continued)

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Combat Vehicles (cont)			
Vehicle, combat, engineer, full-tracked, 165-mm gun: M728 (basic M601A1 tank) FSN 2350-795-1797	115.0	27	62
Armored Vehicle-Launched Bridges			
Launcher, M48 tank chassis, transporting	96.0	19	45
Launcher, M48 tank chassis, transporting, with bridge, armored vehicle-launched, scissoring-type, Class 60, 60-foot	128.0	26	36
Launcher, M60A1 chassis, transporting	86.3	15	36
Launcher, M60A1 chassis, transporting, with bridge, armored vehicle launched, with scissoring-type, Class 60: 60-foot	115.9	22	51
Carriers			
Carrier, cargo, tracked, 6-ton: M548	28.0	18	43
Carrier, command post, light-tracked:			
M577	23.9	17	40
M577A1	24.4	17	40
Carrier, command and reconnaissance, armored:			
M114A1	14.7	12	28
M114	14.7	12	28
Carrier, guided missile equipment, full-tracked: M47E2 w/e (PERSHING), FSN 1450-831-6942	11.9	11	26
Carrier, 107-mm (4.2-inch) mortar, self-propelled: M84	47.1	15	37
Carrier, personnel, full-tracked, armored: M59	42.6	14	34
Carrier, personnel, full-tracked, armored:			
M113	22.6	16	39
M113A1	23.4	17	40
Carrier, utility, articulated: M571	8.0	7	19
Recovery Vehicles			
Recovery vehicle, full-tracked, heavy: M51	120.0	21	50
Recovery vehicle, full-tracked, medium: M88	112.0	20	47
Recovery vehicle, full-tracked, light, armored M578	54.0	21	49

Table 3-7. VCI values for selected military vehicles (continued)

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Amphibious Vehicles			
Bridge, float, mobile assault, amphibious, (French)	59.4	122	267
Lighter, amphibious, self-propelled, cargo, 5-ton, LARC-V: design 8005	31.0	30	68
Lighter, amphibious, self-propelled, cargo, 15-ton, LARC-XV: design 8004	75.0	77	170
Transporter, amphibious, self-propelled, with superstructure, end bay mobile assault bridge (MAB)	60.4	33	291
Transporter, amphibious, self-propelled, with superstructure, interior bay mobile assault bridge (MAB)	59.4	129	280
Missile Vehicles			
Launcher, rocket: 762-mm, truck-mounted, (Honest John System):			
(M139 chassis), M386, w/e	40.2	29	65
(M139D chassis), M289, w/e	47.7	37	82
Loader-transporter, guided missle, XM501E2 w/e (HAWK) FSN 1450-768-7046	9.7	32	73
Loader-transporter, guided missile, XM501E3 w/e (HAWK) FSN 1450-066-8873	9.5	32	72
Transporters	76.0	72	160
Transporter, CONEX, 6x6, 16-ton			
Trucks			
Truck, cargo, ¾-ton, 4x4:	7.4	27	61
M37	7.4	27	61
M37B1	9.6	19	44
Truck, cargo, 1¼-ton, 6x6: M561	17.2	27	61
Truck, cargo, 2½-ton, 6x6: M34	19.2	26	59
Truck, cargo, 2½-ton, 6x6: M35A1			
Truck, cargo, 2½-ton, 6x6:			
M36	18.9	27	61
M36C	18.9	27	61
Truck, cargo, 2½-ton, 6x6: M135	18.7	27	61
Truck, cargo, 2½-ton, 6x6: M211	18.6	26	59
Truck, cargo, 5-ton, 6x6: M41	29.8	30	67
Truck, cargo, 5-ton, 6x6: M54	30.6	30	67
Truck, cargo, 5-ton, 8x8: M656	25.6	18	42
Truck, cargo, 8-ton, 4x4: M520	43.4	43	97

Table 3-7. VCI values for selected military vehicles (continued)

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Trucks (cont)			
Truck, cargo, 10-ton, 6x6:			
M125	49.5	37	84
M125A1	49.5	37	84
Truck, dump, 2½-ton, 6x6: M47	19.2	28	64
Truck, dump, 2½-ton, 6x6: M59	19.5	27	62
Truck, dump, 2½-ton, 6x6: M215	18.6	26	59
Truck, dump, 2½-ton, 6x6: M342A2	20.6	29	65
Truck, dump, 5-ton, 6x6:			
M51	32.7	32	72
M51A2	32.7	32	72
Truck, maintenance, ¾-ton, 4x4: M201B1	8.8	29	66
Truck, maintenance, earthboring, 2½-ton, 6x6: V18A/MTQ	19.5	30	67
Truck, maintenance, telephone construction and maintenance, 2½-ton, 6x6 V17A/MTQ	18.8	29	65
Truck, platform, utility, ½-ton, 4x4:			
M274	2.1	14	32
M274A1	2.1	14	32
M274A2	2.1	14	32
M274A3	2.1	14	32
M274A4	2.1	14	32
Truck, tank, fuel-servicing, 2½-ton, 6x6, 1,200-gal:			
M217 (w/600-gal)	19.6	27	62
M217C (w/600-gal)	19.6	27	62
Truck, tank, fuel-servicing, 2,500-gal, 4x4:			
M559 (GOER) (w/2,500-gal)	43.2	49	111
(empty)	27.6	24	55
Truck, tank, gasoline, 2½-ton, 6x6			
1,200-gal: M49 (w/600-gal)	18.8	26	60
M49C (w/600-gal)	18.8	26	60
Truck, tank, water, 2½-ton, 6x6, 1,000-gal: M50	18.9	27	61
Truck, tank, water, 2½-ton, 6x6 1,000-gal: M222	18.0	25	57
Truck, tractor, 2½-ton, 6x6: M48 (w/o payload)	11.8	20	46
Truck, tractor, 2½-ton, 6x6: M221 (w/o payload)	11.7	20	46
Truck, tractor, 2½-ton, 6x6: M275 (w/o payload)	11.6	20	46
Truck, tracto,: 5-ton, 6x6:			
M52 (w/o payload)	17.8	21	48
M52A1 (w/o payload)	17.8	21	48

Table 3-7. VCI values for selected military vehicles (continued)

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Trucks (cont)			
Truck, tractor, 10-ton, 6x6:			
M123 (w/o payload)	28.9	21	48
M123C (w/o payload)	30.2	22	50
M123D (w/o payload)	30.2	22	50
Truck, tractor, 12-ton, 6x6: MS6A1 (w/o payload)	48.9	35	79
Truck, tractor, wrecker, medium, 5-ton, 6x6: M246 (w/ payload)	44.8	32	73
Truck, utility, ¼-ton, 4x4: M38	3.6	21	48
Truck, utility, ¼-ton, 4x4:			
M38A1	3.5	20	47
M38A1C	3.5	20	47
Truck, utility, ¼-ton, 4x4: M151	3.1	19	44
Truck, utility, ¼-ton, 4x4, lightweight: M422A1	2.6	19	44
Truck, van, expansible, 2½-ton, 6x6: M292	25.1	34	76
Truck, van, shop, 2½-ton, 6x6: M109A1	21.0	29	65
Truck, van, shop, 2½-ton, 6x6: M220	20.4	27	62
Truck, wrecker, crane, 2½-ton, 6x6: M108	19.8	28	63
Truck, wrecker, light, 2½-ton, 6x6: M60	24.5	33	74
Truck, wrecker, medium, 5-ton, 6x6: M62	33.3	33	74
Truck, wrecker, medium, 5-ton, 6x6: M543	34.4	34	76
Truck, wrecker, 10-ton, 4x4: M553, (GOER)	40.2	42	94
Earthmoving Tractors			
Tractor, full-tracked, low-speed, DED, heavy dbp, w/bulldozer, w/scarifier:			
IH Model TD-24-241, FSN 2410-542-2338	54.2	18	43
Caterpillar Model D-8, FSN 2410-542-4882	51.0	17	41
Tractor, full-tracked, low-speed, DED, medium dbp, w/bulldozer, cable PCU Caterpillar Model D-7, FSN 2410-277-1280	35.8	16	38
Tractor, full-tracked, low-speed, DED, medium dbp, w/angledozer, w/scarifier, IH Model TD-18-182, FSN 2410-541-7655	39.8	14	34
Tractor, full-tracked, low-speed, DED, medium dbp, w/angledozer, w/scarifier, IH Model TD-20-200, FSN 2410-542-2498	40.2	15	36
Tractor, full-tracked, low-speed, DED, light dbp, w/bulldozer, w/scarifier, Caterpillar Model D-6, FSN 2410-542-4206	16.0	17	40

Table 3-7. VCI values for selected military vehicles (continued)

Tracked Vehicles			
Vehicle Description	**Vehicle Weight (in thousands of pounds)**	**VCI_1**	**VCI_{50}**
Earthmoving Tracators (cont)			
Tractor, full-tracked, low-speed, DED, light dbp, w/bulldozer, w/scarifier, w/winch, Caterpillar Model D-4, FSN 2410-843-6374	17.3	21	49
Tractor, full-tracked, low-speed, DED, light dbp, w/bulldozer, PCU Hydraulic crane, Caterpillar Model 933, FSN 2410-555-1756	16.0	20	48
Tractor, full-tracked, low-speed, DED, medium dbp, w/bulldozer, w/scarifier:			
Allis Chalmers HD-16M, FSN 2410-078-6483	48.5	16	38
Caterpillar Model D-7, FSN 2410-782-1130	48.5	16	38
Tractor, full-tracked, 5-ton universal ballastable, (Universal Engineer Tractor)	36.0	16	39
Tractor, wheeled, industrial, DED, medium dbp, w/bulldozer front:			
Clark Model 290 M, FSN 2490-088-9384	54.2	34	77
Caterpillar Model 830M, FSN 2420-806-0031	54.2	28	65
Cranes and Loaders			
Crane shovel, basic unit, crawler-mounted: 2-cu-yd, 40-ton, Baldwin-Lima-Hamilton, FSN 3810-230-3821	132.6	21	50
Crane shovel, basic unit, crawler-mounted: Baldwin-Lima-Hamilton, FSN 3810-221-2327	38.2	14	33
Crane shovel, basic unit, crawler-mounted: 10-ton, ¾-cu-yd, "UNIT" Model 1,020-yd, FSN 3810-255-7593	35.0	9	21
Crane shovel, crawler w/catwalk; 2-cu-yd, 40-ton, Bucyrus-Erie, FSN 3810-263-3068	132.6	21	50
Crane, revolving, crawler-mounted: 30- to 40- ton, Thew shovel L-82	103.0	22	52
Crane, wheel-mounted, ⅜-cu-yd, 5-ton, DED, 4x4, rough terrain, air-transportble, Koehring Model M7,FSN 3810-828-4457	16.0	40	89
Crane, wheel-mounted, 20-ton, ¾-cu-yd, rough terrain, 4x4, FSN 3810-060-2735	60.5	42	93
Loader, bucket-type: full-tracked, DED, 3-cu-yd per min, Haiss Model 77-PC	23.0	20	47

LESSON 3

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. There is only one correct answer for each item. When you complete the exercise, check your answer with the answer key that follows. If you answer any item incorrectly, study again that part of the lesson that contains the portion involved.

1. What three soil parameters must be determined in order to describe the Atterberg limits of a soil?

2. True or False. An interlocking soil structure is characteristic of poorly graded soils.

3. If the average CI of a layer of soil before remolding was 74 and after remolding was 70, what is the RI of the soil layer?

4. What USCS symbol should be assigned to a soil with the following characteristics?

   The percent of material retained on a Number 200 sieve: 43 percent
   The LL of material passing a Number 40 sieve: 70
   The PL of material passing a Number 40 sieve: 30

5. True or False. The field sampling of soils for trafficability purposes ideally takes place under the average natural condition for that soil.

6. The RCI of the critical layer for a single pass of a container express (CONEX), 6x6, 16-ton transporter over a particular region is 68. The VCI for one pass of the transporter is 72. Will the underlying soil support the passage of the specified vehicle?

7. What is the USCS symbol assigned to highly organic materials that may be identified by their distinctive colors, odors, or fibrous textures?

8. The CI is a measure of the shear strength of a particular layer of soil in its __________________________ state.

9. What USCS symbol should be assigned to a soil with the following characteristics?

   The percent of material retained on a Number 200 sieve: 92 percent
   The percent of coarse material retained on a Number 4 sieve: 82 percent
   The gap-graded coarse fraction
   The LL of material passing a Number 40 sieve: 50
   The PI of material passing a Number 40 sieve: 30

10. The difference in moisture content between the LL and the PL of a soil is called the ______________________.

LESSON 3

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback
1.	PL (page 3-8, paragraph 3.a.) LL (page 3-8, paragraph 3.a.) PI (page 3-8, paragraph 3.a.)
2.	False (page 3-24, paragraph 2.a.(1))
3.	0.946 (page 3-33, paragraph (last))
4.	CH (page 3-14, paragraph b; page 3-8, paragraph b; page 3-9, figure 3-4; page 3-8, paragraph (3))
5.	False (page 3-26, paragraph (a))
6.	No (page 3-36, paragraph (e))
7.	Pt (page 3-15, paragraph (3))
8.	Undisturbed (page 3-31, paragraph (b))
9.	GP-GC (page 3-8, paragraph 4.a; page 3-8, paragraph 4.a.(1); page 3-10, paragraph (c); page 3-8, paragraph b; page 3-9, figure 3-4)
10.	PI (page 3-8, paragraph (3))

If you experienced difficulty with any of the questions, review the appropriate sections before proceeding with the final examination.